EVAPORATION, BANK STORAGE, AND WATER BUDGET AT LAKE POWELL

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July 1977

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LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

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ABSTRACT

Evaporation estimates were made for Lake Powell, the largest reservoir in the Upper Colorado River Basin, using mass-transfer methods based on data recorded on four raft stations on the lake in 1973 and 1974. These estimates and longer term data from a land-based evaporation pan indicate an evaporation rate of 70 inches (178 centimeters) per year and an average net-evaporation loss of 500,000 acre-feet per year from the reservoir.

Investigations of bank storage indicate that primary porosity and permeability are almost entirely responsible for the bank storage and that secondary porosity is negligible. The bank storage during the period 1963 through 1976 totalled about 8.5 million acre-feet. The rate at which water entered bank storage decreased as the reservoir level stabilized. Although the rate decreases, the total amount will still increase. There is significant return flow when the level drops appreciably.

Evaporation and bank storage have taken about 9 percent of the inflow to Lake Powell in the 14-year period (1963 through 1976). Some limited amount of the bank storage would be recoverable as the lake level declines.

INTRODUCTION

Lake Powell is the largest reservoir in the Upper Colorado River Basin (UCRB). It begins just above the 1922 Colorado River Compact Point at Lee Ferry, the accounting point for division of the waters between the Upper and Lower Basins (Figure 1). The reservoir contains over 80 percent of the potential storage volume in the UCRB (Upper Colorado River Commission, 1970, p. 28), and began filling behind Glen Canyon Dam in March 1963. It has increased in volume almost every year since then until the 1976-1977 drought. Lake Powell is a multipurpose reservoir built to store water, generate hydroelectric power, and provide the public with outdoor recreation facilities. The lake's large storage volume permits water to be reserved in the Upper Basin in wetter years in order to meet downstream commitments (to the Lower Basin and Mexico) in drier years. Its hydroelectric power contribution is a significant addition to the energy supplies in the region. The recreation facilities provide still-water recreation in an arid region where there are many national parks, national monuments, and scenic areas that all contribute to the tourist industry in the UCRB (Figure 2).

The creation of Lake Powell inundated about 250 miles (402 kilometers) of river canyon (Murdock and Calder, 1969, p. 1) where there was some boating and fishing activity, and replaced it with a still-water recreation facility about 250 square miles in surface area (Murdock and Calder, 1969, p. 2). At the close of 1976 the reservoir contained approximately 20,636,000 acre-feet of active storage and 1,998,000 acre-feet of dead storage. In addition to this surface storage there also is a considerable amount of water in bank storage, and a more accurate determination of that figure is one of the reasons for our study.

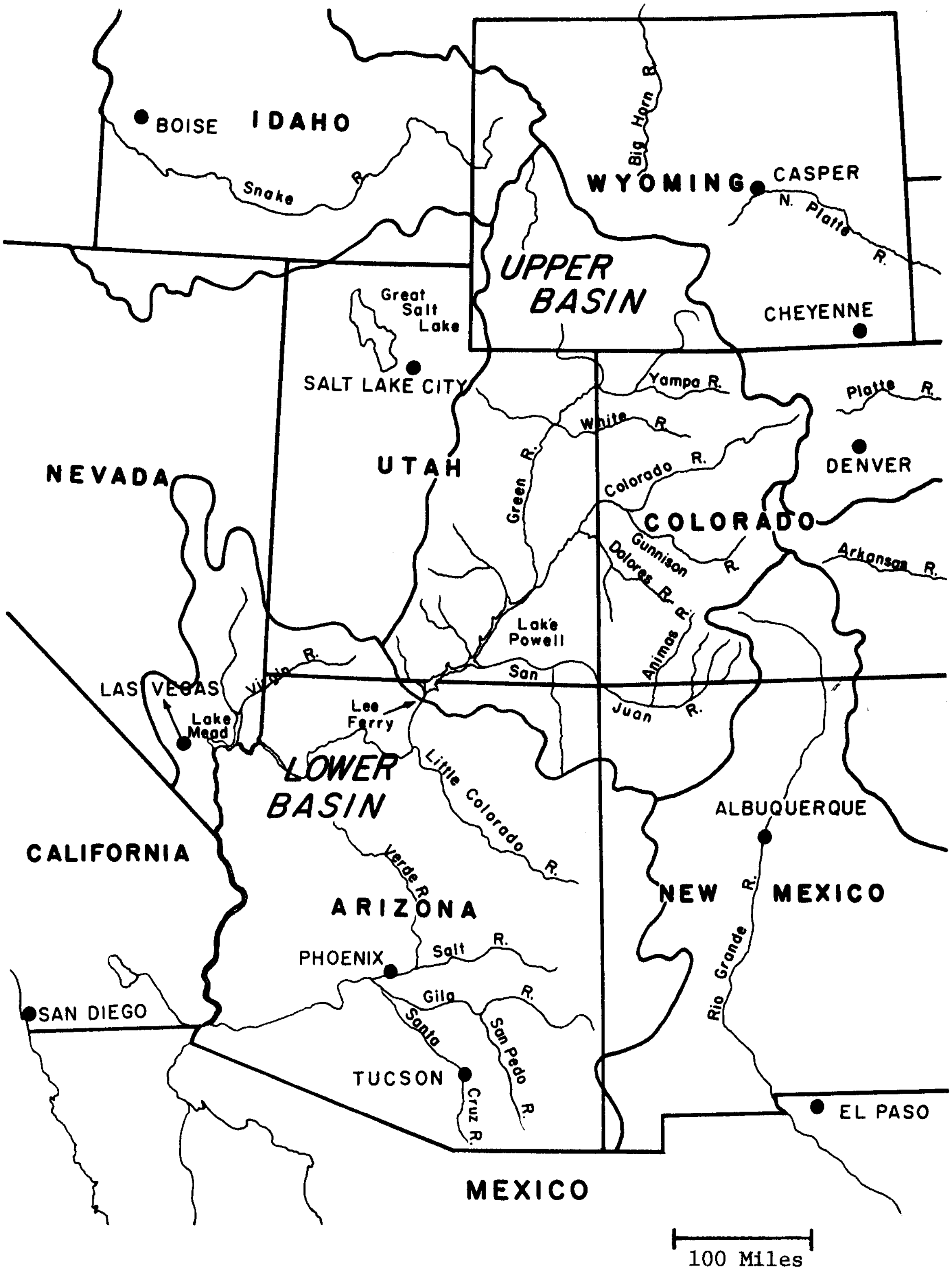


Figure 1: Map of the Colorado River Basin

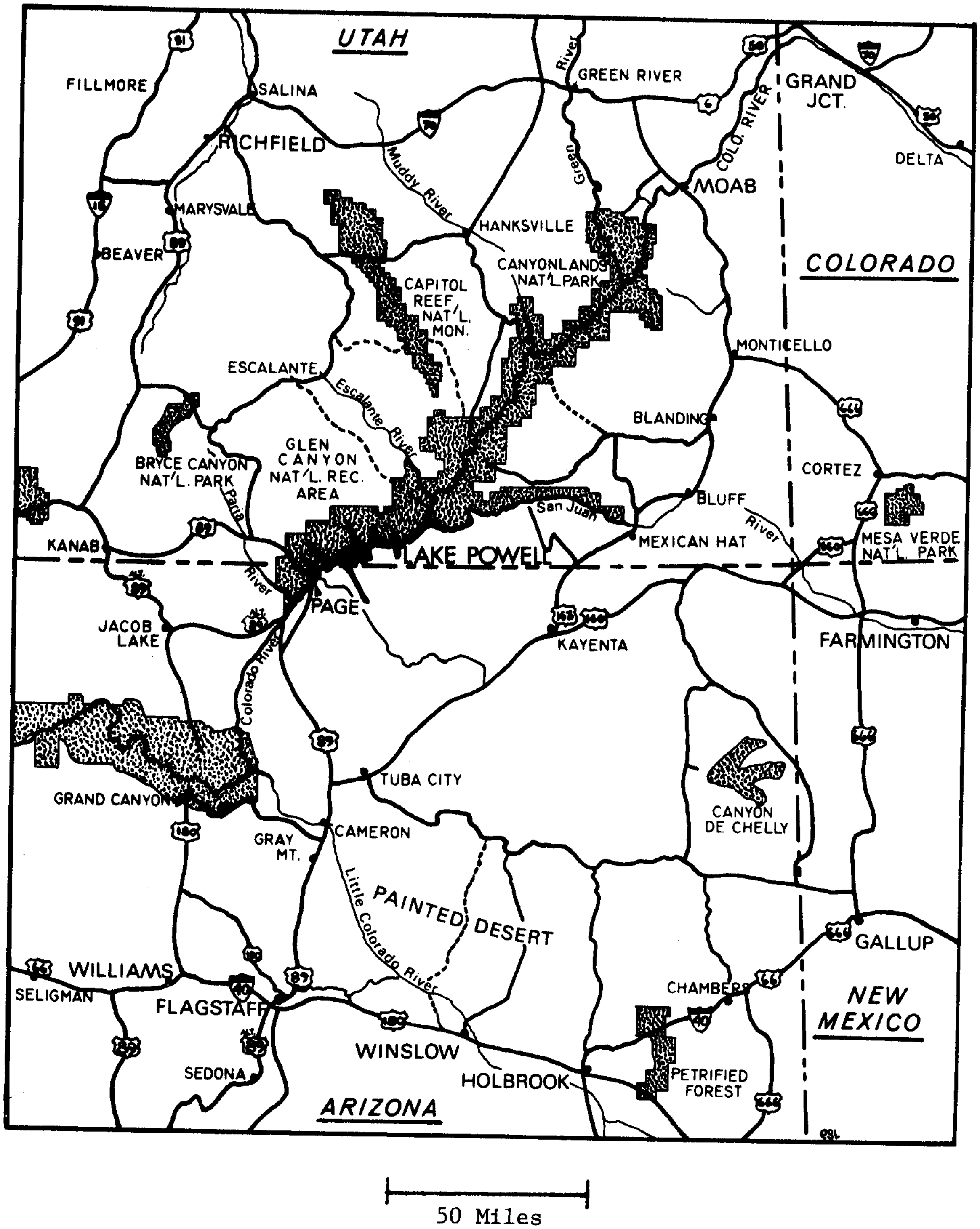


Figure 2: Map of the Lake Powell Region

The creation of Glen Canyon Dam and Lake Powell affected the water budget for this section of the Colorado River system by changing the amount of water lost to evaporation from the reservoir area and water entering bank storage in the surrounding geologic formations next to the reservoir. Evaporation is measured as an annual loss of water from surface-water resources and is the unavoidable price for surface storage of water in an arid environment.

Bank storage is the substantial loss of water, by infiltration into the reservoir banks, from a river system during the filling period of a reservoir. Once the reservoir has achieved an operating level, the water fluctuates around that level. After the initial filling period, the water enters bank storage at a considerably slower rate and there may even be significant return flow when the reservoir level drops appreciably. Bank storage may contribute significantly to the water-storage capability in the UCRB. For the past 14 years since the reservoir began filling, the annual loss of water to bank storage and evaporation has averaged approximately 9 percent of the annual total Upper Basin river flow into Lake Powell.

Evaporation can be calculated by measuring meteorological parameters (air and water temperatures, wind, relative humidity, and radiation) at the lake. These parameters can be used (in relatively standard methods of calculation) to determine the evaporation rate from the surface of the reservoir. Bank storage is more difficult to determine and must be measured indirectly, taking into account the hydrogeologic setting. Once the evaporation rate is determined, one can attempt to estimate bank storage by modeling the overall water budget. Data from wells near the lake can be used to interpret the hydrogeology of the area. To install enough wells to actually observe the bank storage effects would require an enormous capital expenditure. To model the overall water budget, one can measure the inflow and outflow from the reservoir and the change in water storage. Evaporation can be calculated from measurements made near or at the lake. The values obtained can then be used in a water budget model to estimate bank storage. Except for direct precipitation input, other contributions or losses to the overall water budget are relatively negligible with respect to evaporation and bank storage.

The studies discussed in the following section were undertaken with the cooperation of the Bureau of Reclamation which provided valuable assistance in solving the logistics problems, supplied some of the instrumentation for the evaporation study, and underwrote the costs of drilling and testing the wells used to aid in the hydrogeologic analysis.

EVAPORATION

One of the earliest estimates of evaporation in the Upper Colorado River Basin was contained in U.S. Geological Survey (USGS) Professional Paper 272-D (Meyers and Nordenson, 1962, plate 3). Interpolating the data in the map gives an evaporation rate of approximately 4-1/2 feet (1.4 meters) per year in the vicinity of Lake Powell. The USGS evaporation rate map is based on a map prepared by Kohler, Nordenson, and Baker (1969) which used Class A evaporation-pan data with pan-to-lake coefficients applied. The map data covered the period from 1946 to 1955.

Myers and Nordenson (1962, p. 74) state:

> "The accuracy of the map on an areal basis is considered to be generally good, particularly in the vicinities of the control points where the error should be within about 10%, plus or minus. Somewhat less accuracy, however, must be expected for point values in uncontrolled areas."

During their study the Class A pan station nearest Lake Powell was Piute Dam in central Utah, over 100 miles (161 kilometers) to the northwest (U.S. Department of Commerce, 1956, p. 67). Therefore, the accuracy of the USGS 1962 estimate for the Lake Powell area is uncertain.

Other evaporation-loss estimates were made by the Bureau of Reclamation prior to the construction of Lake Powell. These unofficial pre-lake estimates were based on evaporation-pan data adjusted by a pan coefficient to arrive at an annual rate (Wilson, 1962). This estimate, based mostly on distant evaporation-pan data, was surprisingly accurate. Pan data from Hite, Mexican Hat, and Moab, Utah, and Page, Arizona, were used. Wilson's estimate of 66.2 inches (1.68 meters) of water evaporated per unit of water-surface area is the gross evaporation rate value without any adjustment for the influence of precipitation. With a full reservoir the gross evaporation was calculated to be 898,100 acre-feet per year (Wilson, 1962, p. 4).

The Lake Powell Research Project (LPRP) at its inception considered evaporation to be an important parameter in the water budget at Lake Powell and planned a comprehensive study of the evaporation. A cooperative agreement was negotiated with the Bureau, and the LPRP Lake Evaporation Subproject was started in 1971. In 1972 we evaluated the instrumentation we would use, and in the beginning of 1973 we installed our equipment. We began collecting data on May 10, 1973; the site was a raft at Wahweap Bay. The first full day of recorded data was May 11, 1973. The data collection system was run by LPRP personnel through the end of 1974 at which time it was turned over to the Bureau of Reclamation for continued operation.

DATA COLLECTION SYSTEMS

We originally intended to determine evaporative loss by both mass-transfer and energy-budget methods, however, most of our efforts were directed towards the mass-transfer analyses. The data stations for our system were on four rafts on Lake Powell (Figure 3), three of which had been installed by the Bureau of Reclamation prior to our using them. A fourth raft was installed for our use at the extreme northern portion of the lake where formerly there was no data station. One raft was at Wahweap Bay, a second was at Padre Bay. Both these rafts were near the southwestern end of the lake. A third raft was centrally located at Bullfrog Bay, and a fourth was near Hite, at the northern end of the lake.

Each raft had its own recording system, a Sierra Model 700 Field Data Station. These systems collect input signals from various sensors, process them, and record them on a cassette tape recorder. The recording system was in an aluminum case; connections to the sensors were through an open side panel and the case was in a weatherproof steel shelter with a reflective roof. Figure 4 shows the data flow into the recorder system and onto the cassette tape inside the recorder.

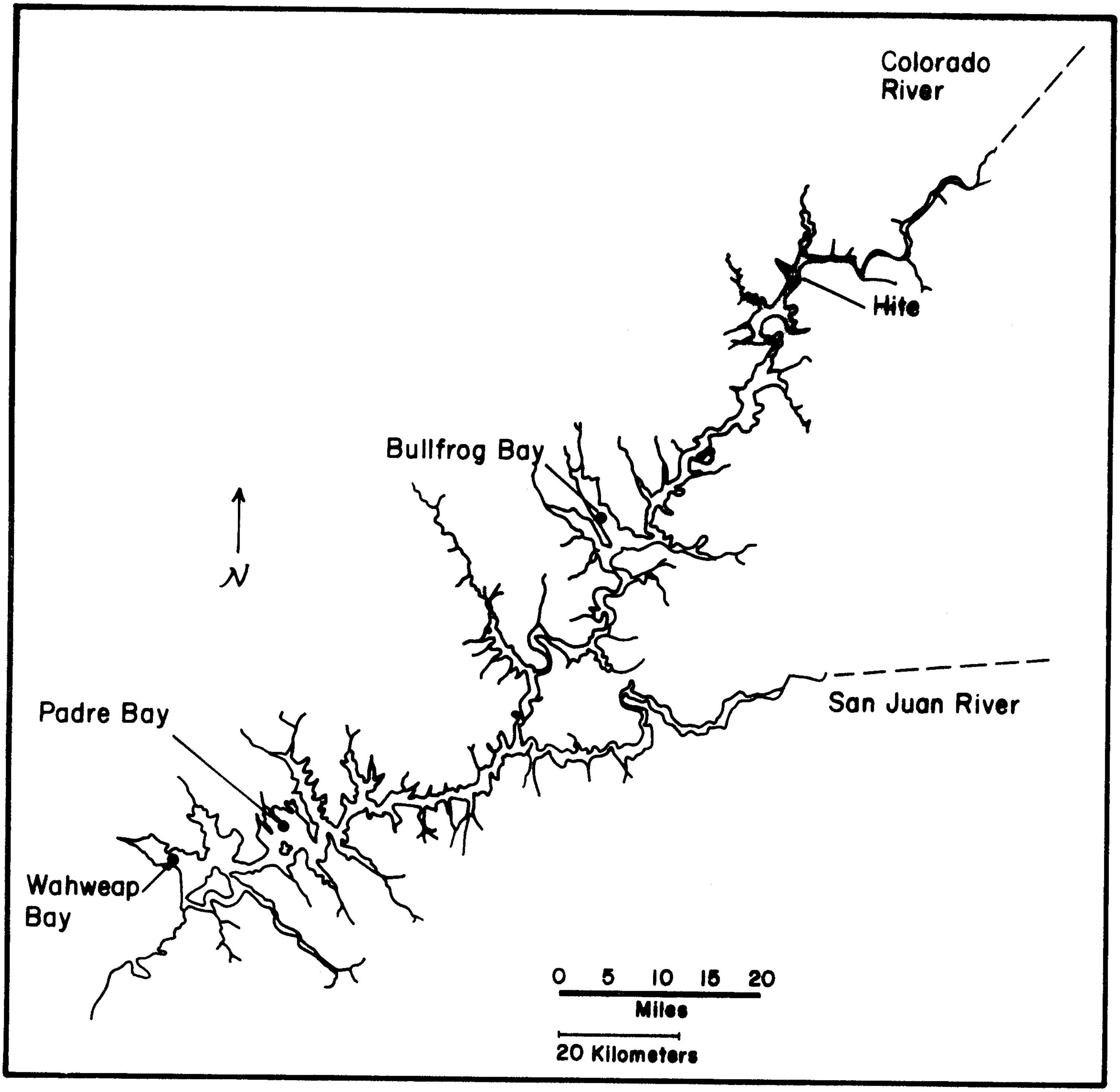


Figure 3: Locations of Data Collection System Rafts for Evaporation Study of Lake Powell

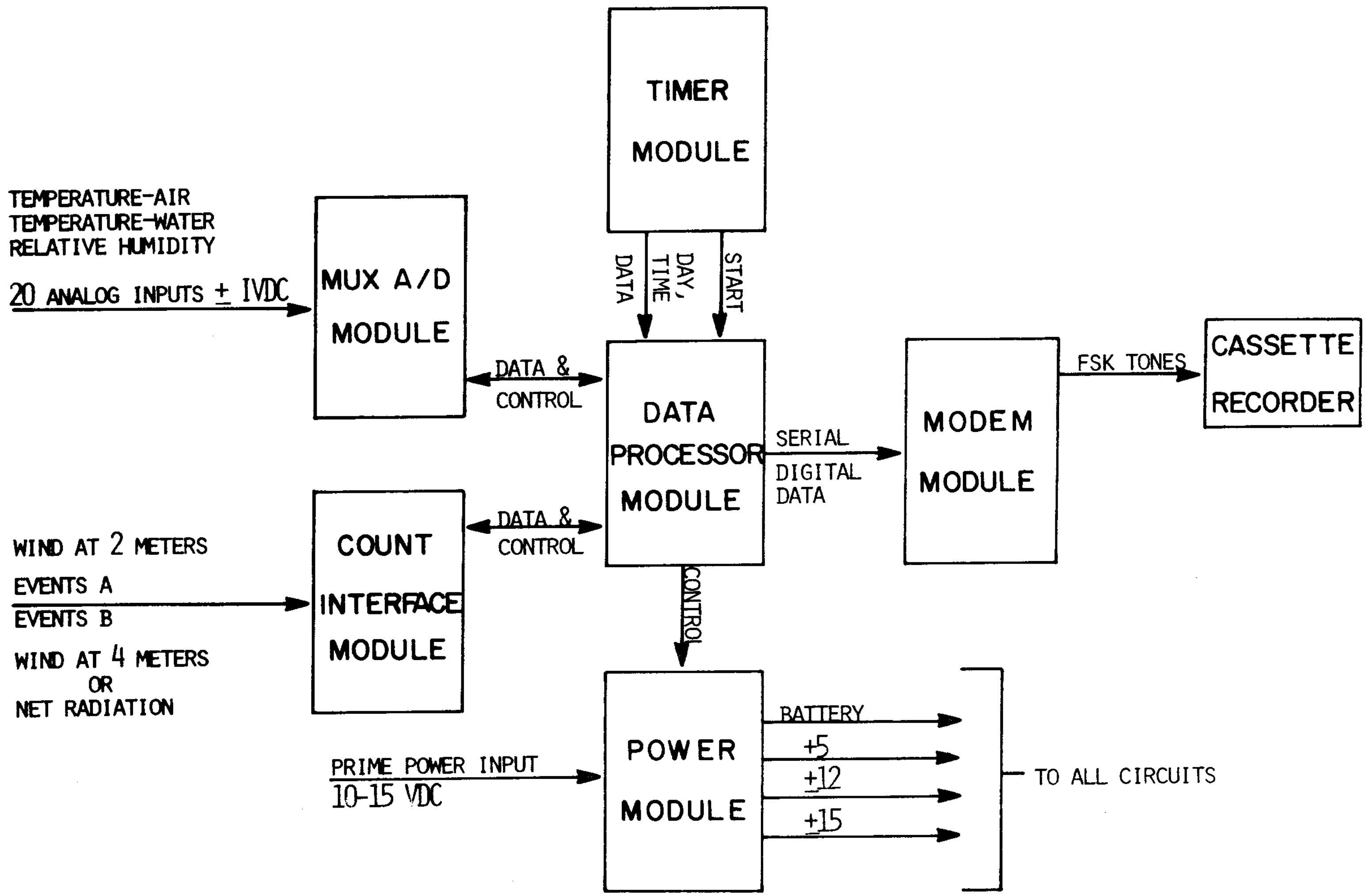


Figure 4: Flow of Meteorological Measurements on Rafts to Cassette Tapes

The recorders were set up to record data from the sensors every hour on the hour, 24 hours per day, and to run continuously for about 30 days. As the timer triggered the station to come on each hour, the station identification number was recorded, as was the day of the year, 1 through 365, and the time of day on a 0- to 23-hour scale. These numbers were followed by the information from the various sensors on each raft.

A brief description follows of how the sensors functioned.

Temperature

There were four thermistor probes per raft: one to measure air temperature at 6.6 feet (2 meters) above the water surface; one for water-surface temperature; and two for additional air- or water-temperature measurements as needed. The air temperature was measured at a height of 2 meters above the water surface because in other evaporation studies this has been a standard elevation to use. Air at this height is considered to be at a representative temperature. The water-surface temperature probe was placed a few centimeters beneath the water surface. The temperature measurements from this probe were slightly cooler than the actual lake-surface temperature on very still days. However, because evaporation is largely a function of air movement (wind moves the moist air away from the lake surface; it is replaced with drier air from the shore which can absorb more water vapor), major evaporation occurs when the wind blows. This same air movement, through the wave action it generates, causes a mixing of the upper levels of the water. Therefore, the temperature a few centimeters below the water's surface is considered representative of this wind-mixed layer, even in fairly low wind periods. During an absolutely calm period, the only way moisture can leave the surface of the lake is by molecular diffusion, which creates a negligible amount of evaporation compared to the amount lost when the wind blows.

Wind

The original anemometers used by the Bureau of Reclamation accumulated the wind measurement between approximately weekly readings. Since averaging parameters on a weekly basis for evaporation calculations can lead to serious errors in calculating evaporation rates (Jobson, 1972, p. 513), we obtained hourly wind measurements. The anemometers used by the Bureau required a fairly high threshold of wind velocity before they would respond. The anemometers purchased and installed for our study were Weathermeasure LW103 (6-cup), which have a threshold of 0.45 mile per hour and a distance constant of less than 2 feet. When we purchased them in 1972, they were the most sensitive cup-type anemometers available. Two of the rafts, those at Bullfrog and Padre Bays, had anemometers situated 13 feet (4 meters) above the lake surface in order to determine the wind gradient. Several of the equations in our early calculations relied upon determining the ratio of the wind measurements at 4 meters to the wind at 2 meters. The Sierra recorders have two channels that can be used to accumulate digital information for devices such as these anemometers; this permits an accumulation of data on the total wind movement (in miles) during the past hour. Therefore when the sample is taken the total wind movement for the past hour is recorded, giving a wind velocity in miles per hour as an average for the past hour.

Relative Humidity

The relative-humidity transducer we used was a Hygrodynamics instrument (No. 15-7012) which operates on the principle of the variable resistance of lithium-chloride-coated wires. The hygroscopic lithium chloride responds to ambient moisture in the atmosphere and the resistance is a function of the moisture content of the lithium-chloride coating. We installed these instruments (in small shelters) at the 2-meter sampling level above the lake's surface.

Radiation

For the purpose of our energy-budget study, two net-radiometers (Fristchen type) were installed, one at the Wahweap Bay raft at the extreme south end of the lake and one at the Hite raft at the extreme north end of the lake. These instruments respond to the following types of radiation: total, direct solar, atmospheric, and radiation reflected, and emitted, from the water surface. These data were accumulated over the course of an hour, and at the end of each hour were recorded as the net amount of radiation that was received by the radiometers at the two stations. Because there are only two channels on the Sierra recorder that can accept the signals from this type of instrument, our options were limited. We decided to have a 2-meter anemometer and radiometer combination on two of the rafts and 2- and 4-meter anemometers on the other two rafts. Unfortunately, the radiometers proved to be too fragile for the lake environment and produced little usable data.

All of these sensors operated continuously and were interrogated every hour on the hour. The recording system, activated by a timer module, interrogated each sensor and recorded all of the information on a cassette tape. These cassette tapes were retrieved approximately every month and were hand-carried to the computer facilities at Lowell Observatory in Flagstaff for data analysis and reduction.

DATA ANALYSIS AND REDUCTION

Figure 5 depicts the data flow from the sensors on the rafts through the cassettes and the flow through the data reduction system at Lowell Observatory. An initial data analysis and reduction system was created to translate the cassette tapes, put them directly on magnetic tape, and calculate evaporation results. However, there were so many problems with the field recording system that to achieve adequate data recovery we had to create an intermediate hard-copy review prior to making the calculations.

This review enabled us to decipher data which were shifted, contained spurious characters, or had other imbedded incoherencies. For example, during one particular time period the Padre Bay recorder initiated the data string, interrupted it midway, and then started reproducing the same data string; however, neither portion was complete. By reviewing the first portion and the second portion it was determined there was an overlap and, by hand, one could punch out data for this time period and recover valid measurements at the lake even though there had been a malfunction in the recorder. There were other occasions when the timers malfunctioned and an intermediate change was made in the data reduction program to compensate for timer malfunctions, the data themselves being accurate. By these different methods the maximum amount of on-site data was extracted from the cassette-tape records.

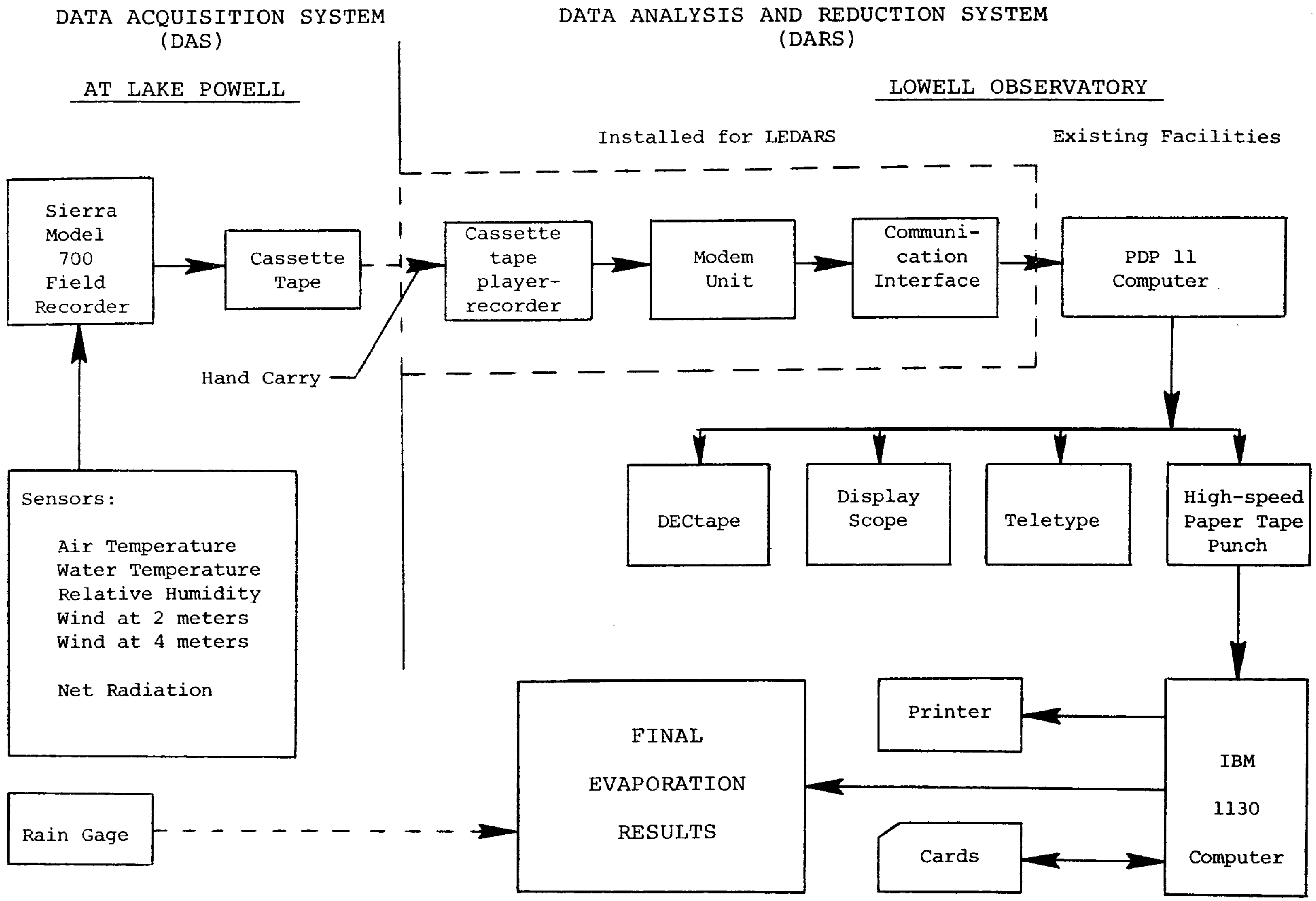


Figure 5: Block Diagram of Lake Evaporation Data Acquisition and Reduction (LEDARS)

Evaporation calculations initially were done two ways. One equation used a ratio of 4-meter and 2-meter wind measurements in an attempt to account for mixing in the air over the lake (Koberg, 1972). However, this method proved to be too sensitive to small changes in either measurement and the 4-meter wind was only measured at two raft stations.

The second equation used a fetch factor and was in the following form (Koberg, 1972):

$$E = \frac{0.0051}{\left(\frac{F + 550}{650}\right)^{0.0342}} \left(\frac{273}{273 + T_o}\right)^2 U^{0.75}(e_o - e_a)$$

where E = evaporation in inches per day

F = fetch in feet (distance from shore to station)

T_o = temperature of water surface

U = wind in miles per hour at 2 meters above lake

e_o = saturation water vapor pressure in millibars at the temperature of the lake surface

e_a = water vapor pressure in millibars at 2 meters above the lake surface

The Koberg (1972) equation was developed by considering evaporation data and rates from the Salton Sea, Dillon Reservoir, Lake Hefner, and a one-acre stock pond in addition to other evaporation and theoretical studies.

In a reservoir the size of Lake Powell, the average fetch is large enough that a standard value can be used and the variation in fetch causes only small changes in the fetch factor. The fetch factor is the expression (from above) $[(F + 550)/650]^{0.0342}$. The standard value of fetch selected for the raft stations was about 1-1/2 miles (1.9 kilometers). This value produces a fetch factor of about

1.09 and is within 1.25 percent of the value of the fetch factors for 1 and 2 miles. This is admittedly a rather arbitrary selection; however, by measurement of map distances this range of 1 to 2 miles is felt to be appropriate and representative for the raft stations and the lake.

EVAPORATION RESULTS

Discussion

We collected data from May 1973 through December 1974. The only stations to produce usable data during 1973 were Wahweap and Padre Bays. The Bullfrog Bay and Hite stations were installed in the summer of 1973 but did not yield any usable data.

Appendix A lists the daily results for Wahweap and Padre Bays for 1973. Estimates were made for missing days in order to complete the data for the months of June through December. Where gaps of 1 or 2 days occurred, the means of the preceding and following 5 days' data (if available) were used to estimate the missing values. Where a longer gap occurred, the ratio between Wahweap and Padre Bay data during concurrent periods of good data was used to adjust the Padre Bay data to estimate values for Wahweap. The ratio for the total overlap period indicates that Wahweap evaporation values equal 1.15 times the Padre Bay values.

The 1974 evaporation data were complete enough for us to derive separate listings for the Wahweap Bay, Padre Bay, Bullfrog Bay, and Hite stations (Appendix B). Wherever possible the measured data from the location in question were used. Where gaps of 1 or 2 days occurred, the mean of the preceding and following 5 days' data was used to represent each of the missing days.

Where gaps of longer duration occurred, the linear trend between the preceding and following 5 days was derived. Ratios were also calculated for longer periods using Wahweap as the standard station. The 1974 ratios follow:

Wahweap equals 1.0278 times Padre Bay
Wahweap equals 1.1132 times Bullfrog Bay
Wahweap equals 0.9934 times Hite

During 1974 all four data stations had been installed and produced the greatest amount of useful data. The Wahweap and Padre Bay stations functioned reasonably well during this year. The Bullfrog Bay and Hite stations functioned sporadically, but yielded enough data to give what we feel are reliable ratios of the evaporation at these upper-lake stations with respect to Wahweap Bay at the southwestern end of the lake. Therefore, we have used 1974 as the reference year.

The total annual evaporation during 1974, as measured at the Wahweap Bay raft, was 68 inches (173 centimeters) (cm), and this is a reasonably complete record. Appendix B shows the results from the various raft stations during the year when they produced sufficient data for calculation of daily evaporation. From the ratios between the various stations and Wahweap Bay, it can be seen that Wahweap and Padre Bay stations produced essentially the same evaporation measurements. There was a 3-percent difference, Wahweap Bay being slightly greater. However, 3 percent is certainly within the error in measurements and calculations. The measurement at Bullfrog Bay was about 10 percent less than that at Wahweap Bay. The Hite station produced approximately the same evaporation value as Wahweap during the times when their data collection overlapped.

Days in which evaporation data were available for Wahweap and Padre Bays were considered simultaneously, and we found that the greatest number of overlapping points were obtainable if the 1973 data were summed on a 4-day basis and the 1974 data on a 5-day basis. The 1974 Bullfrog Bay and Hite evaporation data were each also compared to the 1974 Wahweap data, and these were summed on a 5-day basis.

We made comparison studies of these same locations on an hourly, daily, 10-day, and 30-day basis. Correlations were poorer for the hourly and daily values, and the 10- and 30-day values had fewer overlap periods than did the 4- and 5-day sums.

Figures 6 and 7 are the plots of the results of these compilations. Figure 6 shows the linear trend between the 1973 evaporation data from Padre Bay and those of Wahweap. A trend is visible, but the points are scattered due to lack of data for that year. The 1974 Padre Bay and Wahweap evaporation data are also plotted in Figure 6 and show better agreement. Figure 7 compares the 1974 Bullfrog Bay evaporation data to Wahweap evaporation data. The 1974 data in all three cases are linear and less variable than are those of the 1973 plot.

We undertook this compilation to establish the relationship between the four study sites, the reliability of the Wahweap Bay site as a basis for comparison, and to further justify the use of 1974 data as a standard.

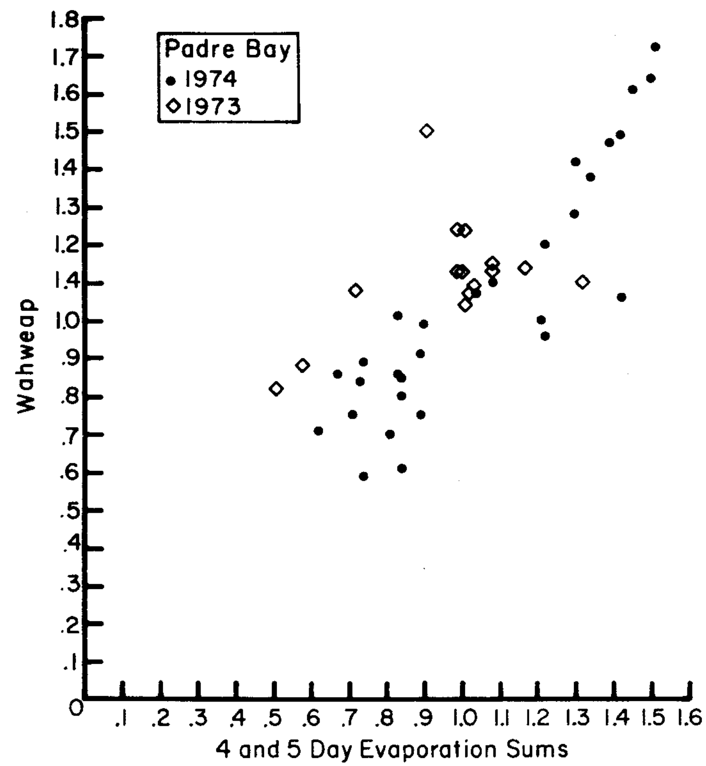


Figure 6: Comparison of Evaporation Data Between Wahweap Bay and Padre Bay Raft Stations

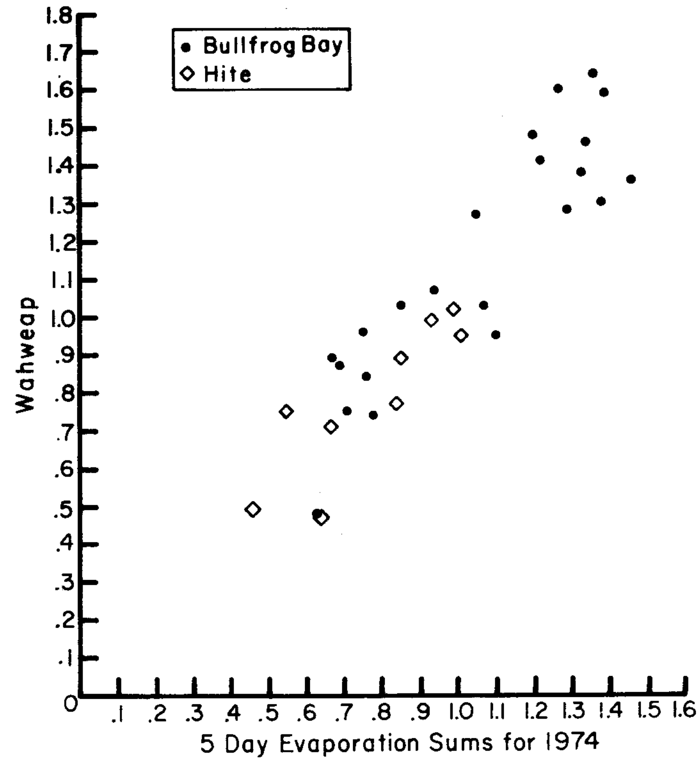


Figure 7: Comparison of Evaporation Data Among Wahweap Bay, Bullfrog Bay, and Hite Raft Stations

Because most of the surface area of Lake Powell lies in the lower portion in the vicinity of Wahweap, Warm Creek, and Padre Bays, we feel that measurements in these areas represent the evaporation rate for the majority of the surface area of Lake Powell. The San Juan arm and the Upper Colorado arm are represented by the measurements at Hite, indicating that the evaporation there is essentially the same. Although Bullfrog Bay is centrally located, it is a separate bay away from the main channel and may not be representative of larger bays (such as Good Hope in the upper portion of the lake) which are close to or part of the main channel. Therefore, we have assumed that Wahweap Bay, Padre Bay, and Hite are representative of the major portion of the lake, and since the three data-station rafts produced essentially the same evaporation data, these sites can serve as the main index for evaporation at the lake. Because the maintenance of the Wahweap Bay station was more frequent due to its location, we decided to use this site as the standard station rather than to use a mean of Padre and Wahweap Bays' data.

Assuming that our interpretation of the lake situation is correct, the 1974 evaporation figure at Wahweap of 68 inches is an annual figure for that year. Only the Wahweap and Padre Bay stations yielded enough data for monthly values for 1974, and these data are plotted in Figures 8 and 9.

The next question to be answered is: Was 1974 a typical year or is that value higher or lower with respect to what the evaporation rate might be in an average or normal year? The only long-term evaporation measurements available for this region are pan-evaporation measurements. There is one pan at Wahweap Bay (on land about 3 miles--4.8 kilometers--away from the lake station), and this pan is judged to be in

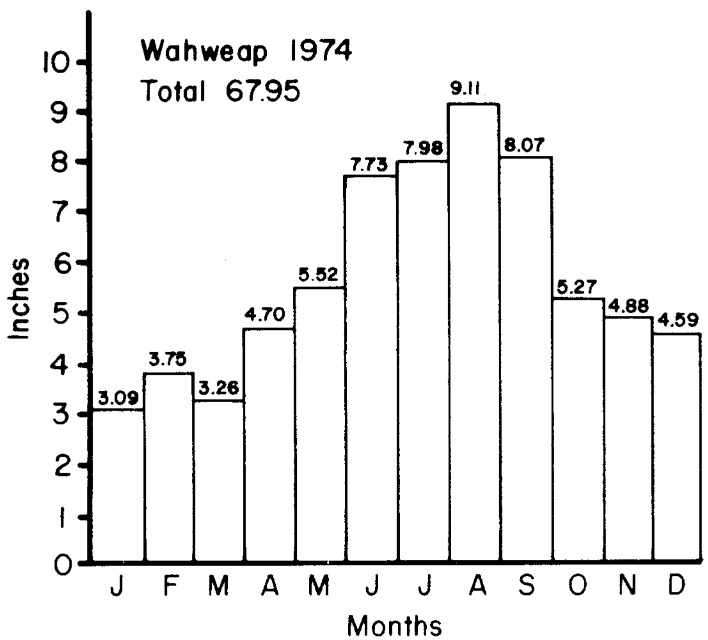


Figure 8: Monthly Evaporation Data, Wahweap Bay, 1974

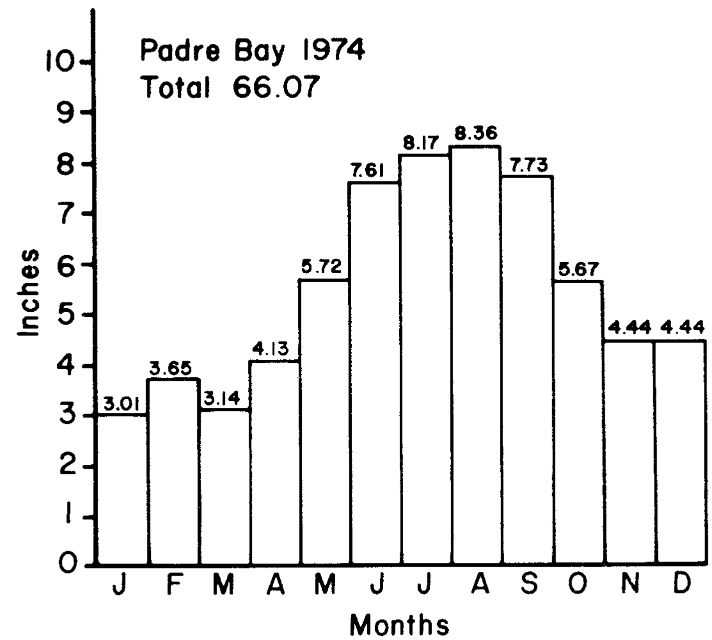


Figure 9: Monthly Evaporation Data, Padre Bay, 1974

a reasonably good location. Therefore it can be used as an index to place 1974 in a context of other years to see if it is representative. There is another evaporation pan at Page, Arizona (several miles away from the Wahweap site); however, this pan is enclosed in a Cyclone fence with many other meteorological instruments. We believe there is interference among these instruments, in that they block the wind and overshadow each other. This second evaporation pan consistently yields much lower evaporation rates than does the Wahweap pan. Examination of the wind data shows that the wind at the Page pan is considerably less than at the Wahweap pan, and we feel that one major reason for this is the blocking of the wind by the other instruments and by the Cyclone fence. Therefore, we feel that the Page pan is not at a good location for the purpose of our study.

We obtained the pan evaporation data for the Class A pan at Wahweap, Arizona, from the U.S. Weather Bureau (Table 1). The monthly sums from 1961 through 1975 were provided by the Bureau; however, because 1961 data were absent for 5 months, we did not include data from that year. Where data were not available for a particular month of the year, the mean pan evaporation for that month from 1962 through 1975 was used to complete the table of total pan evaporation. The number of years for which data were available to compute the mean is also included in Table 1.

Figure 10 shows the Wahweap pan evaporation rate in inches for the period 1962 through 1975. The averages and the evaporation rates for 1973 and 1974 are shown as separate curves. Inspection of these curves indicates that 1974 was fairly close to the average year, although the total for the year is slightly lower than the average. During 1974 the pan

Table 1: Total Pan Evaporation in Inches at Wahweap, Arizona (1962-1975)[a]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1962	2.08	2.93	6.07	12.01	15.83	17.36	19.96	18.28	12.21	6.82	3.07	2.69	119.31
1963	2.08[b]	3.15	6.99	10.38	16.17	17.39	20.72	13.90	10.31	7.43	3.65	2.69[b]	114.86
1964	2.08[b]	3.03[b]	6.25	9.89	14.68[b]	16.40	17.96	17.22	13.14	9.55	3.90	2.69[b]	116.79
1965	2.08[b]	3.66	6.19	8.62	14.54	14.36	15.33	16.39	13.06	7.49	3.72	2.69[b]	108.13
1966	2.08[b]	2.11	7.49	11.96	15.88	19.22	18.52	18.13	11.67	7.98	4.11	2.69[b]	121.84
1967	2.08[b]	3.03[b]	6.51[b]	10.92	13.02	15.54	16.41	14.18	10.50	8.16	4.37	2.69[b]	107.41
1968	2.08[b]	3.03[b]	6.79	9.00	14.63	17.41	15.93	12.71	12.76	6.99	4.19	2.69[b]	108.21
1969	2.08[b]	3.31	5.97	9.74	15.76	15.57	15.89	14.88	11.12	7.09	3.76[b]	2.69[b]	107.87
1970	2.08[b]	3.03[b]	7.70	10.86	16.55	17.16	15.78	14.62	12.79	7.24	3.76[b]	2.69[b]	114.26
1971	2.08[b]	3.03[b]	6.51[b]	10.82	13.77	17.42	20.05	15.06	10.98	7.11	3.76[b]	2.69[b]	113.28
1972	2.08[b]	3.03[b]	6.51[b]	12.16	15.95	15.54	16.64	12.67	11.13	7.51[b]	3.76[b]	2.69[b]	109.67
1973	2.08[b]	3.03[b]	5.15	9.59	13.06	15.04	15.43	15.36	11.22	8.05	3.84	2.69[b]	104.54
1974	2.08[b]	3.03[b]	6.51[b]	10.60	15.41	17.07	15.25	14.58	11.30	6.62	3.02	2.69[b]	108.16
1975	2.08[b]	3.03[b]	6.51[b]	8.32	10.26	14.71	15.40	12.79	10.26	7.16	3.76[b]	2.69[b]	96.97
Mean	2.08	3.03	6.51	10.23	14.68	16.44	17.08	15.05	11.60	7.51	3.76	2.69	110.66
Number of Years in the Mean													
	1	5	9	14	13	14	14	14	14	13	9	1	

a = The pan was usually not operated all 12 months of each year. When there was no measurement available the mean of the rest of the years for that month was used in calculating the estimated values. Original pan data from U.S. Weather Bureau Climatological Data for Arizona.

b = Estimated data.

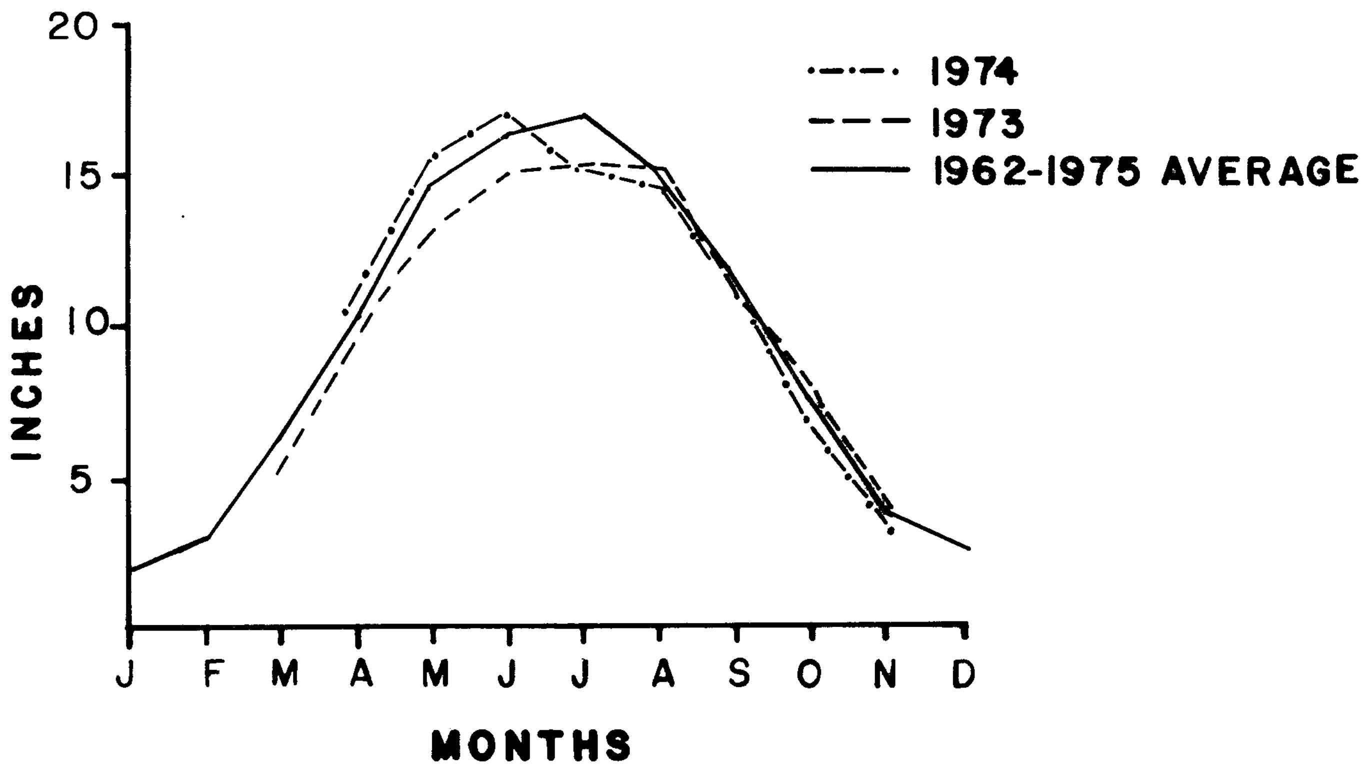


Figure 10: Evaporation as Measured at Wahweap: 1962-1975 Average

evaporation at Wahweap was 2-1/2 inches (6.33 cm) lower than the mean. Total pan evaporation for 1973 was 104.54 inches, for 1974 108.16 inches, and the 14-year mean or "average" year was 110.66 inches (266, 275, and 280 cm, respectively). In 1974 the monthly rate was slightly above the normal evaporation in May and June, and slightly below in July. This small difference is probably within the error of measurements; however, it could also indicate that 1974 was slightly below normal.

After looking at the other parameters for 1974 versus average years, we then evaluated the air temperature, precipitation, and wind data available. These comparisons are plotted in Figures 11, 12, and 13. It can be seen that the air temperature for 1974 was slightly above the mean but very close to it. The total precipitation showed that 1974 was about the driest year in the precipitation record, which runs from 1969 through 1976. Figure 13 shows the analogous wind movement. In 1974 it appeared that there was less wind than during the 1962-1972 average period during all the months for which records are available. Therefore, if the evaporation in 1974 were slightly below average, it appears that it would have been due to there having been less wind than in average years.

From these observations and data, we feel that because the difference in pan evaporation data, which is perhaps the best index of normality, is so slight, the value for 1974 is probably representative as a relatively normal year at Lake Powell.

In order to determine evaporation rates for other years for use in our model, we compared the Wahweap raft and pan data on a month-by-month basis to develop pan coefficients

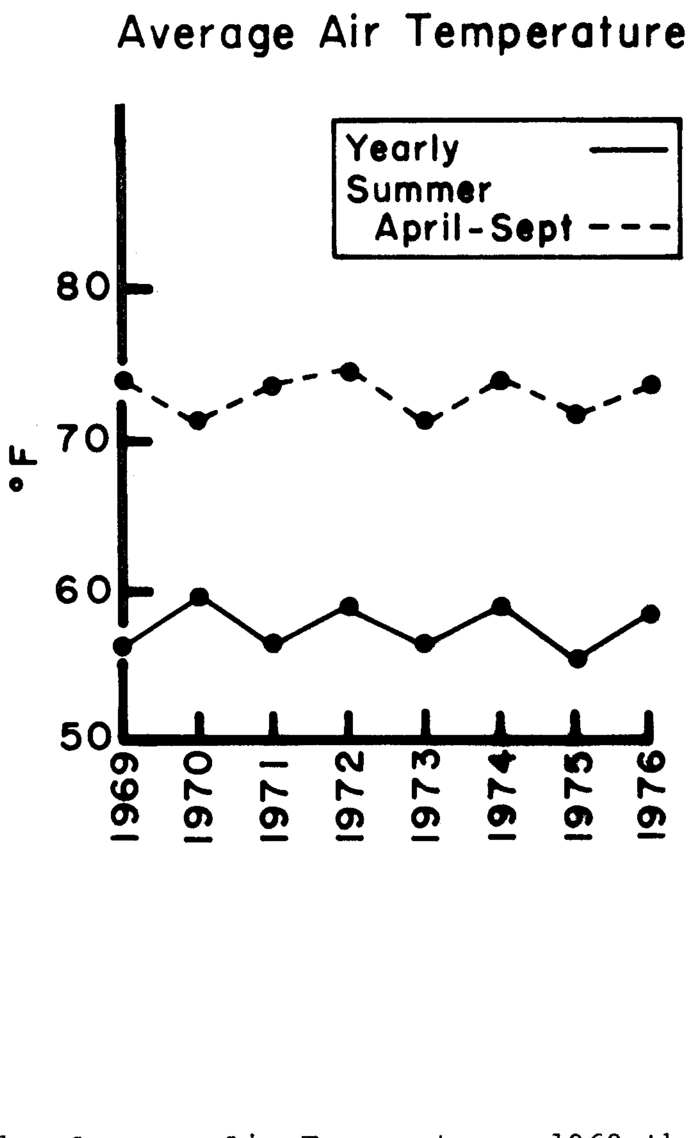


Figure 11: Average Air Temperature, 1969 through 1976

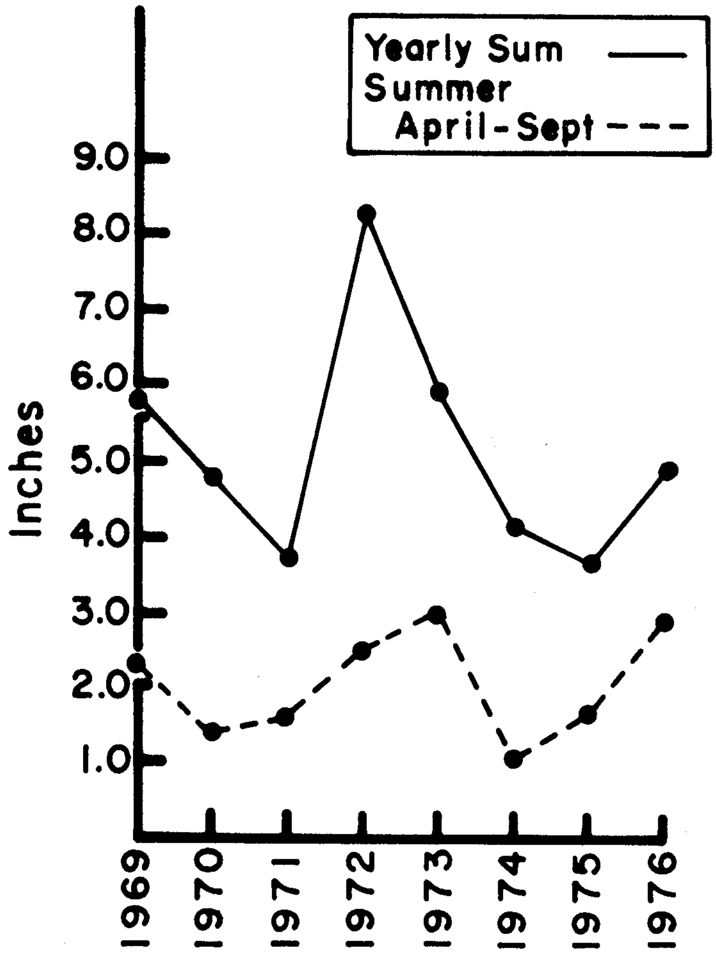


Figure 12: Precipitation at Lake Powell, 1969 through 1976

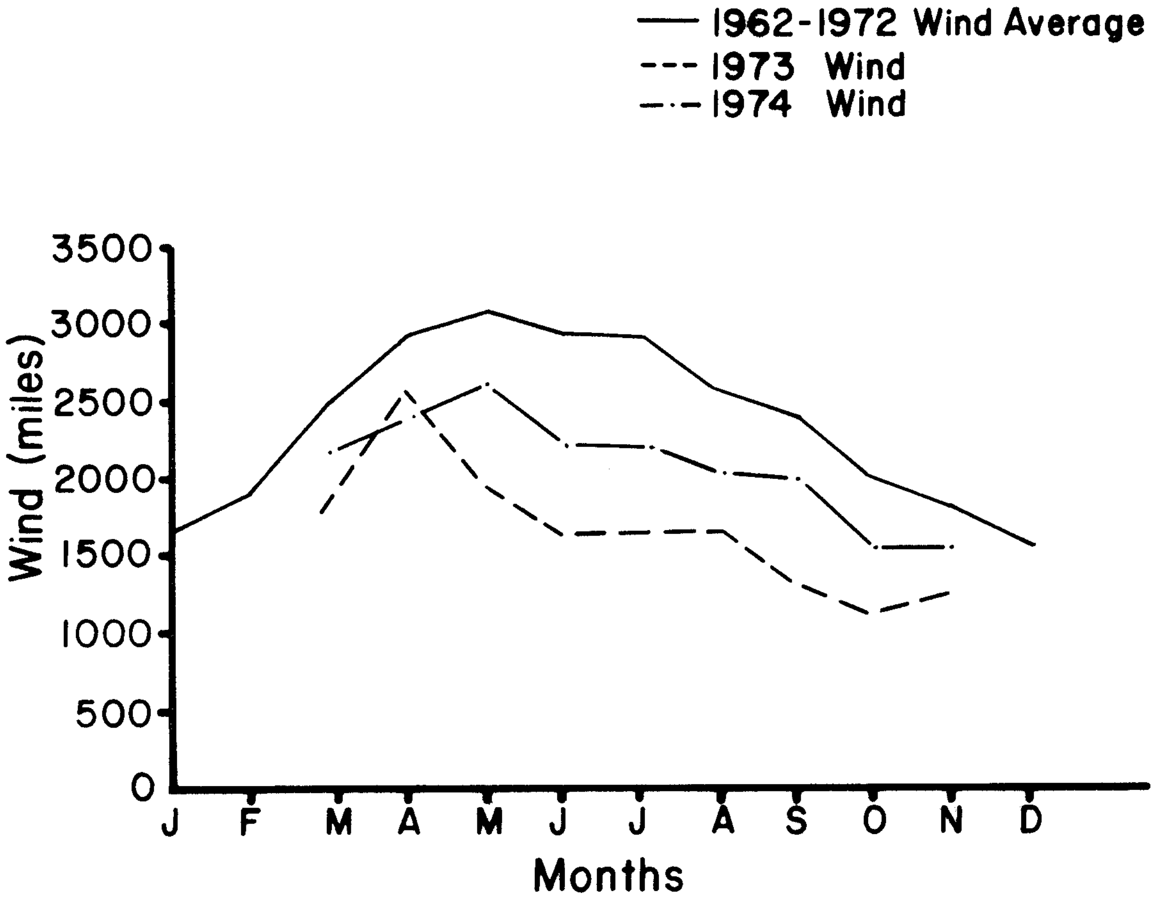
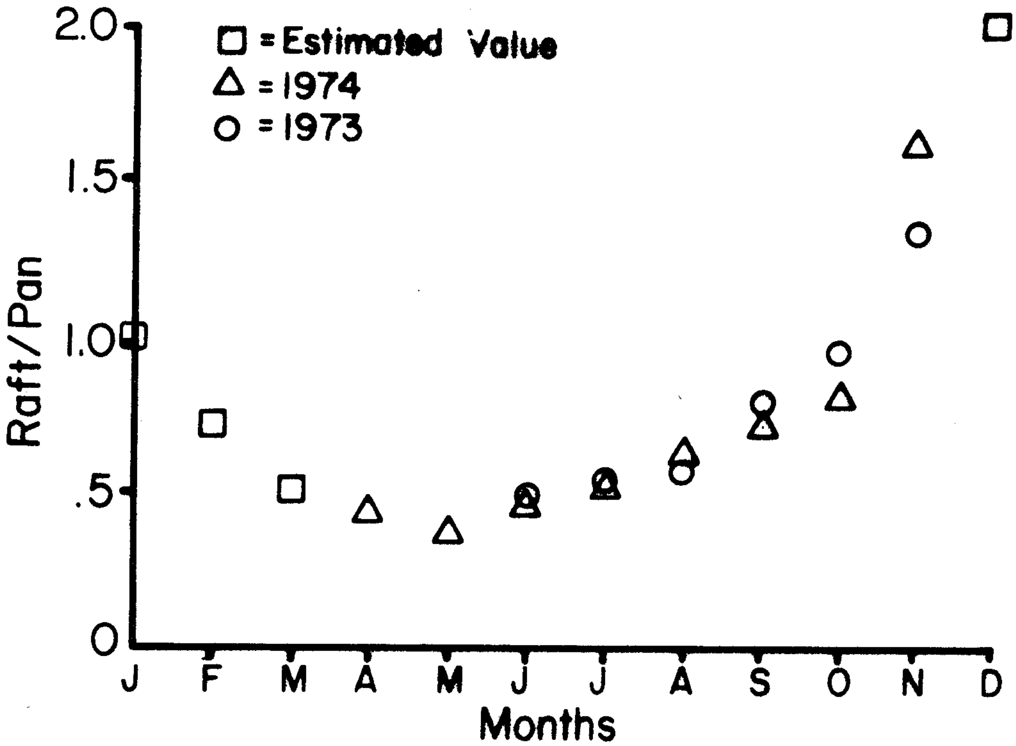


Figure 13: Wind Movement at the Wahweap Evaporation Pan

for the different months of the year. These pan coefficients were calculated for the months of 1973 and 1974 in which there were concurrent pan evaporation data and raft data. Figure 14 shows the pan coefficients and how they varied during the year. The coefficients for June through November were very close to the same values in both 1973 and 1974. Water temperature is a major factor in the difference between pan and raft data. Examining the relationship between water temperature in the pan and surface water temperature at the lake (Figure 15) has permitted us to estimate the pan coefficients for the months (January, February, March, and December) in which there is no overlap of data. Even though there is some uncertainty in the ratios for these months, the evaporation rates for January, February, March, and December are relatively low in comparison to the summer months. On an annual basis this uncertainty may not contribute too much to an error in the annual figure. Also, in considering the pan data there is only one year where data are available for the entire 12 months. Therefore, in constructing the model there was only one value for actually measured pan evaporation for January and for December during the 14 years of record. Table 2 shows evaporation at Lake Powell based on adjusted pan data from the Class A pan at Wahweap for the period 1962 through 1975.

Conclusion

Using the 1974 annual lake evaporation value of 67.95 inches (172.6 cm) and the pan value of 108.16 inches, an annual average can be estimated by adjusting the 1974 lake figure by the same percentage difference between the 1974 pan value and the average pan value, that is +2.26 percent. Thus, the estimate of the average yearly value of total evaporation at Lake Powell is 69.48 inches (176.6 cm), essentially 70 inches (178 cm).



INCHES OF EVAPORATION

1974	Raft	Pan	Raft/Pan	1973	Raft	Pan	Raft/Pan
J	3.09	N.A.	*1.0				
F	3.75	N.A.	*0.7				
M	3.26	N.A.	*0.5				
A	4.70	10.60	.44				
M	5.52	15.41	.36				
J	7.73	17.07	.45	J	7.10	15.04	.47
J	7.98	15.25	.52	J	8.43	15.43	.55
A	9.11	14.50	.63	A	8.76	15.36	.57
S	8.07	11.30	.71	S	8.90	11.22	.79
O	5.27	6.62	.80	O	7.71	8.05	.95
N	4.88	3.02	1.62	N	5.16	3.84	1.34
D	4.59	N.A.	*2.00				

N.A. = Not Available
* = Estimated Value

Figure 14: Evaporation Pan Coefficients for the Wahweap Bay Raft Station and the Wahweap Pan Station

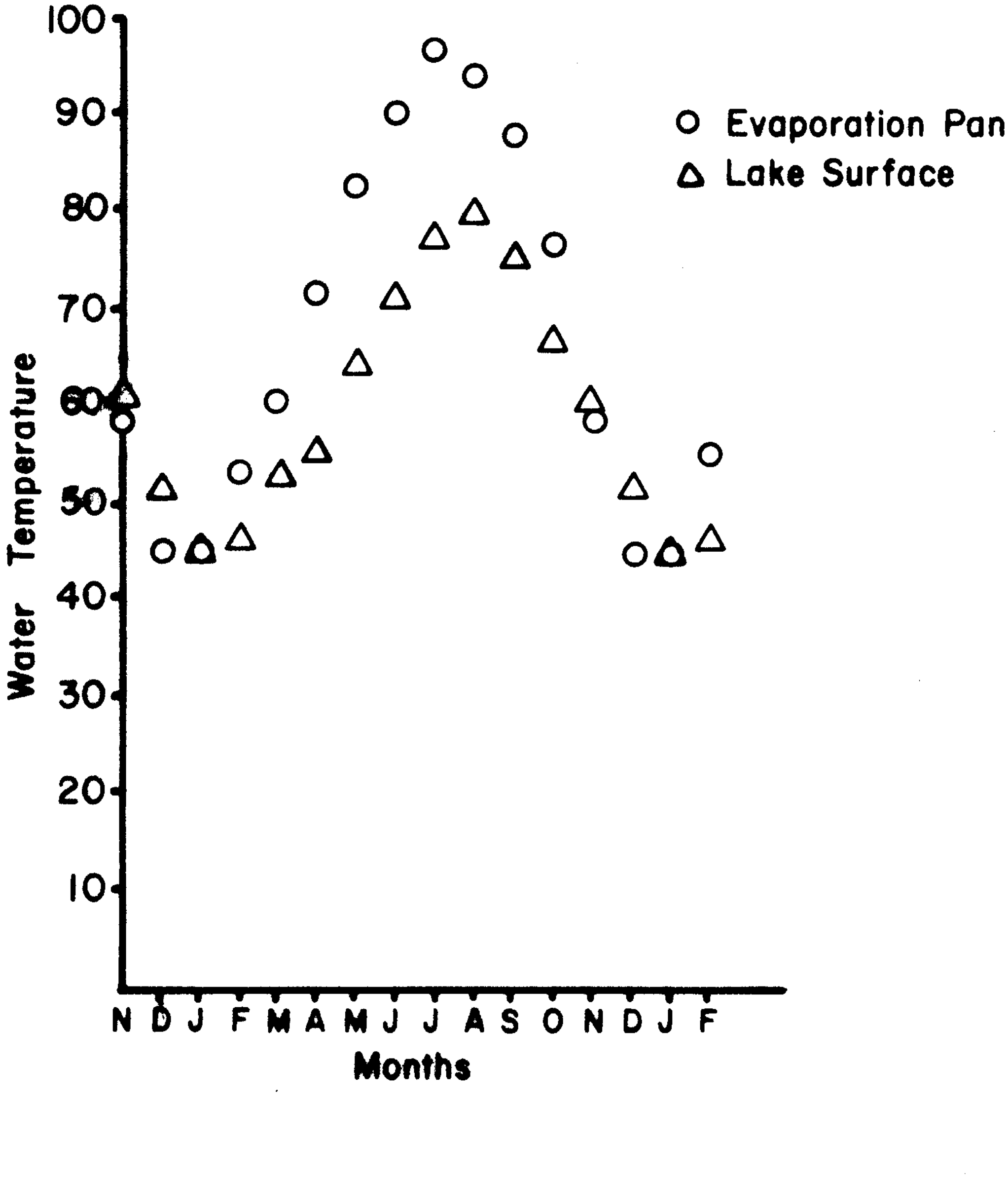


Figure 15: Water-Surface Temperature at Wahweap Bay Raft Station and Evaporation Pan, 1974

Table 2: Evaporation at Lake Powell Based on Adjusted Pan Data from the Class A Pan at Wahweap, Arizona[a]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total
1962	2.08	2.05	3.04	5.28	5.70	7.99	10.78	11.15	9.04	5.79	4.82	5.38	73.1
1963	2.08[b]	2.20	3.50	4.57	5.82	8.00	11.19	8.48	7.63	6.32	5.73	5.38[b]	70.9
1964	2.08[b]	2.12[b]	3.12	4.35	5.28[b]	7.54	9.70	10.50	9.72	8.12	6.12	5.38[b]	74.03
1965	2.08[b]	2.56	3.10	3.79	5.23	6.61	8.28	10.00	9.66	6.37	5.84	5.38[b]	68.9
1966	2.08[b]	1.48	3.74	5.26	5.72	8.84	10.00	11.06	8.64	6.78	6.45	5.38[b]	75.43
1967	2.08[b]	2.12[b]	3.26[b]	4.80	4.69	7.15	8.86	8.65	7.77	6.94	6.86	5.38[b]	68.56
1968	2.08[b]	2.12[b]	3.40	3.96	5.27	8.01	8.60	7.75	9.44	5.94	6.58	5.38[b]	68.53
1969	2.08[b]	2.12	2.98	4.29	5.67	7.16	8.58	9.08	8.23	6.03	5.90[b]	5.38[b]	67.5
1970	2.08[b]	2.12[b]	3.85	4.78	5.96	7.89	8.52	8.92	9.46	6.15	5.90[b]	5.38[b]	71.01
1971	2.08[b]	2.12[b]	3.25[b]	4.76	4.96	8.01	10.83	9.91	8.12	6.04	5.90[b]	5.38[b]	70.64
1972	2.08[b]	2.12[b]	3.25[b]	5.35	5.74	7.15	8.99	7.73	8.24	6.38[b]	5.90[b]	5.38[b]	68.31
1973	2.08[b]	2.12[b]	2.58	4.22	4.70	6.92	8.33	9.37	8.30	6.84	6.03	5.38[b]	66.87
1974	2.08[b]	2.12[b]	3.25[b]	4.66	5.55	7.85	8.24	8.89	8.36	5.63	4.74	5.38[b]	66.75
1975	2.08[b]	2.12[b]	3.25[b]	3.66	3.69	6.77	8.32	7.80	7.59	6.09	5.90[b]	5.38[b]	62.56
Monthly Mean	2.08	2.12	3.26	4.50	5.28	7.56	9.22	9.18	8.58	6.38	5.90	5.38	Annual Mean 69.44

a = The pan was usually not operated all 12 months of each year. When there was no measurement available the mean of the rest of the years for that month was used in calculating the adjusted values. Original pan data from U.S. Weather Bureau Climatological Data for Arizona."

b = Based on estimated values as per note a above.

Net Evaporation

Prior to the creation of Lake Powell, evaporation occurred from the portion of the rivers that are now inundated by its backwaters. By topographic and vegetation analysis (Woodbury et al., 1959) and evaporation estimates, a figure of 227,200 acre-feet per year (Wilson, 1952, p. 4) was computed. In addition to near-stream areas, Wilson (pp. 3 and 4) included in this figure evaporation from the hillside areas near the rivers: 133,581 acres. The evaporation loss was considered to be the effective precipitation of 5.71 inches (14.5 cm) times the hillside area, for a loss of 63,562 acre-feet of water per year.

We do not think this loss should be considered a loss from the river, and therefore we have used a pre-reservoir evaporation loss figure of 163,638 acre-feet per year. The hillside precipitation is salvaged by the reservoir because it now falls directly into the lake and should be considered a gain in the water budget of the reservoir area.

If the reservoir is about two-thirds full (a reasonable operating level), the surface area would be 125,000 acres. The total evaporative loss would be about 724,000 acre-feet per year. If salvaged precipitation and pre-reservoir evaporation are subtracted (60,000 acre-feet and 164,000 acre-feet, respectively), the net evaporative loss would be about 500,000 acre-feet annually at this level.

Evaporation losses are, of course, a function of the surface area of water exposed in the reservoir. This surface area varies from month to month and from year to year as the lake level rises and falls. The figures for the period during which Lake Powell has been modeled are given in the section on the reservoir model. Figure 16 is a plot of evaporation loss as a function of lake level.

BANK STORAGE

Introduction

Bank storage is a phenomenon that occurs in every reservoir, lake, and stream in the world. In many cases the storage and its effects on a water body are negligible. In some cases, such as Lake Powell, the bank storage may be a significant portion of the total storage of the reservoir. In the case of this reservoir, knowledge of the distribution and availability of the stored water is essential in order to determine whether it is real storage, a water loss, or what combination of the two. If the bank storage water is readily available for return to the reservoir as the water level recedes, the storage can be regarded as part of the overall reservoir storage. If it will <u>not</u> return to the reservoir readily, it must be regarded as a water loss.

Because of Lake Powell's large size and complex shoreline, the determination of bank storage volume for the lake is necessarily limited to "residual" estimates in a water budget analysis. If the inflow, outflow, lake volume changes, precipitation, and evaporation are measured or calculated, bank storage at Lake Powell is estimated by the remaining major portion of the total water budget. In order to more fully

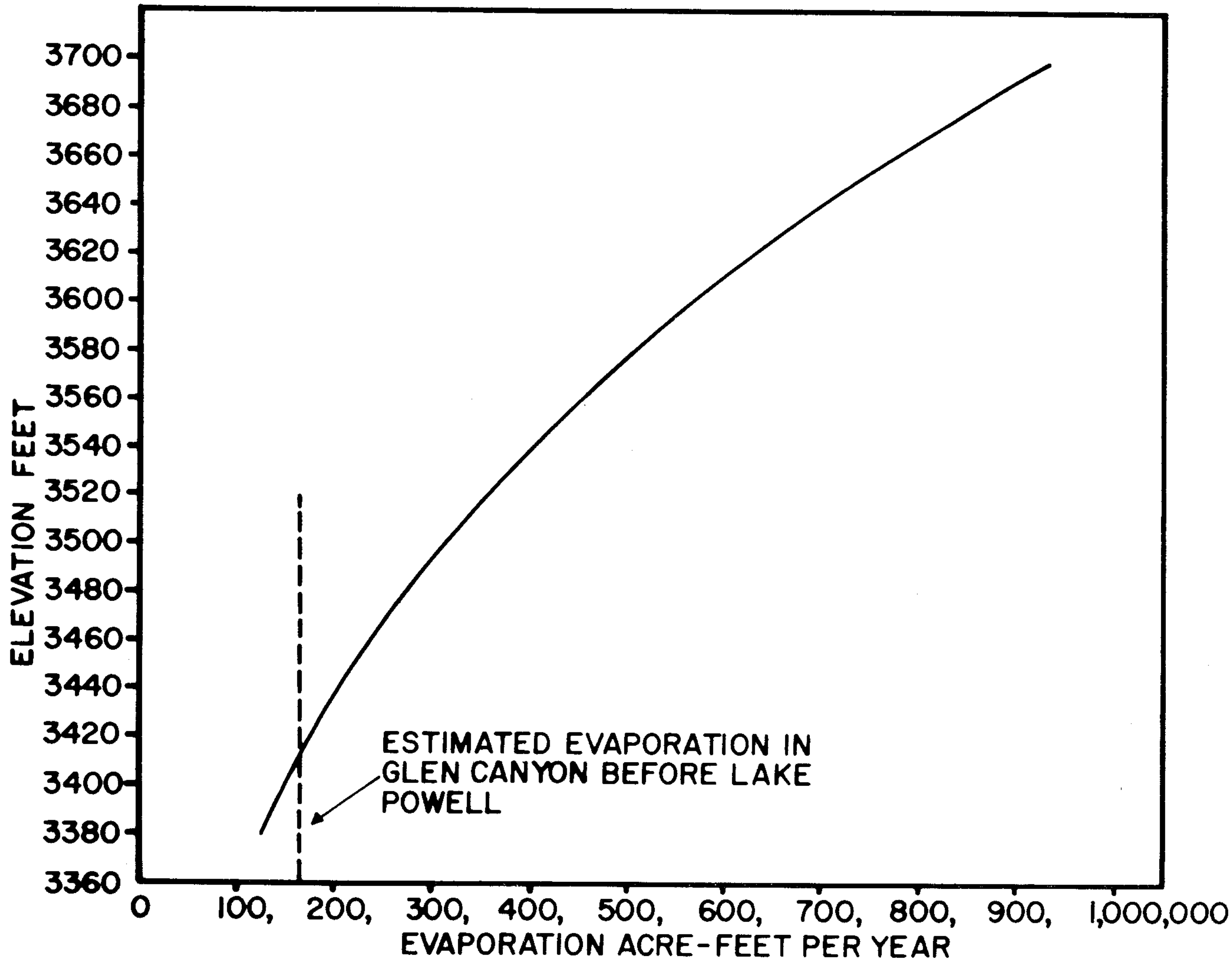


Figure 16: Evaporation at Different Surface Elevations for the Lake Powell Reservoir

understand the bank storage potential of Lake Powell, it is necessary to review the geology and hydrology of the reservoir setting.

Geologic Setting

In the Paleozoic Era, over 200 million years ago, the Lake Powell region was part of a stable shelf extending eastward from the Cordilleran geosyncline. During the late Paleozoic and for part of the Triassic Period, several highlands were elevated. These highlands were the source for much of the sediment deposited in the area which later formed the rock formations exposed at Lake Powell.

The Late Triassic and Early Jurassic were times of major regional structural change which elevated the Cordilleran geosyncline and began the formation of the Rocky Mountain geosyncline that culminated during the Cretaceous time. At this time the area of the Uncompahgre Highlands to the northeast was generally low, and the Mogollon Highlands to the south were high and continued to furnish sediment. As a result, Jurassic and Cretaceous sediments are coarser nearer the Mogollon Highlands to the south of Lake Powell, but thicken and are finer grained to the northeast.

Near the end of the Mesozoic Era, about 60 million years ago, the Laramide orogeny, or mountain building, created the present Rocky Mountains. It also caused the final withdrawal of marine waters and the formation of multiple structural basins in the UCRB area. Regional upwarping in late Tertiary time resulted in the outlining of the Colorado plateaus and nearby mountains and the development of the Colorado River system (Cooley, et al., 1969, p. A12).

The formations within the Lake Powell reservoir basin that are of primary interest to this study range in age from the Pennsylvanian Hermosa Formation to the Jurassic Summerville Formation. The geologic column representing the Lake Powell area is shown in Figure 17. These sedimentary rocks are overlain by thin, discontinuous mantles of weakly consolidated dune sand, alluvium, terrace deposits, and landslide rubble.

Mudstone and siltstone units are distributed throughout the stratrigraphic column and are of marine, fluvial, and lacustrine origin. The sandstone units are composed of very fine- to medium-grained sand and represent fluvial, aeolian, and near-shore marine environments. Some of the sandstone units contain lenticular zones of conglomerate (zones of pebble material). Limestone is relatively uncommon in the area, but where present was deposited in marine and lacustrine environments. Dolomite and gypsum in the form of layers, nodules, or selenite plates, are occasionally associated with the limestone (Cooley et al., 1969, p. A-11).

Formations of the Pennsylvanian age (the Hermosa and the Rico) are transitional from marine limestone, dolomite, and calcareous shale to continental sandstone. These grade upward and interlayer with a rock sequence of Permian age that is of continental, near-shore, and shallow-water marine origin. This sequence includes the Cedar-Mesa Sandstone, a cross-bedded, nonmarine sandstone; the Organ Rock Formation, a red, thin-bedded sandstone and shale; and the White Rim Sandstone, a light-colored, cross-bedded nonmarine sandstone.

Erathem	System	Series	Group, Formation, Member	
Mesozoic	Jurassic	Upper Jurassic	San Rafael Grp.	Summerville Fm (Jsu)
				Entrada Ss. (Je)
		M. Jurassic		Carmel Fm. (Jca)
		Lower Jurassic	Glen Canyon Grp.	Navajo Ss. (Jna)
	Jurassic – – – Triassic	Lower Jurassic – – – Upper Triassic		Kayenta Fm (JTRk)
	Triassic	Upper Triassic		Wingate Ss. (TRwi)
			Chinle Fm (TRc)	
				Shinarump Member (TRs)
		L. Triassic	Moen Kopi Fm (TRm)	
Paleozoic	Permian	Middle - Lower Permian	Cutler Group (Pct)	White Rim Ss (Pwr)
				Organ Rock Fm (Por)
				Cedar Mesa Ss (Pcm)
	Permian – – – Pennsylvanian		Rico Fm (ℙr)	
	Pennsylvanian	Middle Penn.	Hermosa Fm (ℙh)	

GEOLOGIC COLUMN

〜 unconformable

– – indefinite

—— definite

Figure 17: Geologic Formations in the Lake Powell Area (modified from Baars, 1972; Witkind, 1964; Hintze and Stokes, 1964)

The Moenkopi and Chinle Formations unconformably overlie the Permian rocks and consist of soft, poorly cemented mudstone, claystone, shale, ripple-marked siltstone, fluvial sandstone, and conglomerate. The Moenkopi Formation was deposited during the last eastward transgression of the sea from the Cordilleran geosyncline. After a period of widespread erosion, the Chinle Formation was deposited by streams originating in the Mogollon and Uncompahgre Highlands (Cooley et al., 1969, p. A12).

The Shinarump member of the Chinle is a sandstone and conglomerate sandstone comprising subrounded to subangular, fine- to coarse-grained quartz sand and pebbles which are generally poorly sorted. The member is a maze of channel deposits which in most places are firmly cemented by calcareous and siliceous materials (Cooley and Hardt, 1961, p. 62).

The Chinle underlies the downstream two-thirds of the reservoir at an average 400 feet (122 meters) below the bottom of the Navajo Sandstone and occurs throughout much of the San Juan arm of the reservoir. The effect of the impervious nature of the Chinle Formation is discussed in this Bulletin in the Hydrology of Bank Storage section.

The Glen Canyon Group, a sequence of orange-red and grayish red sandstone and siltstone beds, includes in ascending stratigraphic order: the nonmarine, cross-bedded Wingate Sandstone, the primarily fluvial Kayenta Sandstone, and the nonmarine, cross-bedded Navajo Sandstone.

The Navajo and Wingate Sandstones (consisting predominantly of well-sorted, rounded to subrounded, pitted quartz grains) display large-scale cross-bedding, and are aeolian in origin. In contrast, the tightly cemented sandstone and silty sandstone of the Kayenta Formation were deposited by streams that flowed from eastern highlands (Cooley et al., 1969, p. A-14; Murdock and Calder, 1969, p. 3).

The widespread occurrence and physical characteristics of the Navajo Sandstone, particularly its sorting, grain size (0.17-millimeter average diameter) (0.007-inch), and poorly cemented nature, make it the most important aquifer in the reservoir basin. It is friable and contains small pore spaces 0.03 millimeter (0.001 inch) in average diameter. Consequently, it is absorptive due to capillarity and is highly permeable.

The Navajo Sandstone is remarkably uniform over wide areas. It occurs in outcrops from the Echo Cliffs (just southwest of Glen Canyon) almost continuously for 108 miles 174 kilometers) along the Colorado River and about 6 miles (10 kilometers) along the San Juan River. It is 1200 to 1800 feet (400 to 600 meters) thick and has been incised an average of 500 feet (164 meters) by the Colorado River to form the walls of Glen Canyon. It does not come in contact with reservoir water in far upstream areas of either the San Juan or the Colorado River because its base is above elevation 3700 feet (1200 meters), the normal maximum pool elevation for the reservoir.

Jurassic rocks consist of marine limestone, shale, calcareous sandstone, and gypsum of the Carmel Formation, nonmarine siltstone and sandstone of the Entrada Sandstone, and siltstone of the Summerville Formation. These formations comprise the San Rafael Group which was deposited on either side of the Jurassic shoreline which advanced into the area from the north (Cooley et al., 1969, p. A-14).

Unconsolidated sediments, mainly of Quaternary age, are the alluvial, terrace, landslide, and aeolian deposits. They form a discontinuous permeable mantle over large areas of the reservoir basin. The aeolian deposits consist chiefly of quartz-sand dunes and windblown silt lacking dune form. Landslide deposits are gravity-induced and the alluvium is found along active streams (Stokes and Hintze, 1964).

Geologic Structure

The regional dip or inclination of the geologic formations in the Lake Powell area is less than 10 degrees to the southwest. Superposed on the regional dip are many folds of small and large amplitudes. The larger folds or monoclines (Monument Uplift, Echo Cliffs Uplift, San Rafael Swell, Circle Cliffs Uplift) are asymmetrical drape folds, in which the sedimentary rock layers are draped over high-angle faults in the Precambrian crystalline basement (Figure 18).

These larger folds control the movement of water in the sedimentary rocks and divide the area into hydrologic basins named for the structural basins formed in the lowest part of each fold. Thus, the immediate Lake Powell area occupies part of the Blanding, Henry, and Kaiparowits hydrologic basins (Cooley et al., 1969, p. A-19). These three hydrologic basins interconnect to form a structural basin largely underlain by impervious Chinle Formation as described in the Hydrology of Bank Storage section.

The Echo Cliffs monocline defines the downstream limit of the Kaiparowits Basin. At the monocline axis, the

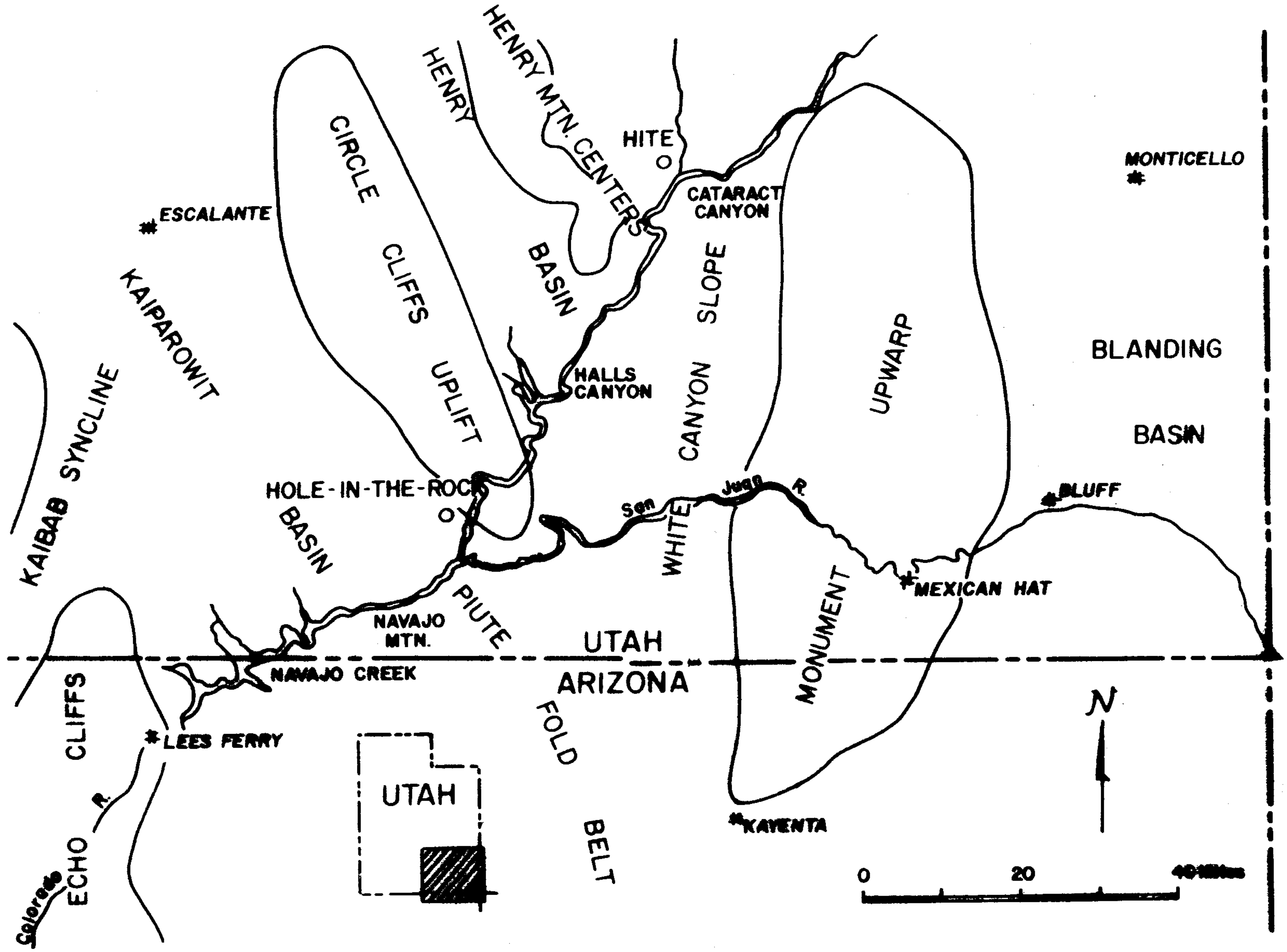


Figure 18: Map of Major Geological Structural Features Near Lake Powell and Locations of Test Wells at Hole-in-the-Rock and Hite

formations dip upstream about 20 degrees, gradually flatten, and gently undulate throughout the basin. The formations reverse direction and increase the steepness of dip as the axis of the Circle Cliffs Uplift is approached, thereby defining the upstream limits of the Kaiparowits Basin. The reservoir walls, for about 60 river-miles within this area, are almost entirely composed of Navajo Sandstone. The Circle Cliffs Uplift brings older rocks, including the Chinle Formation, to the surface for a few river-miles.

The downstream limits of the Henry Basin are also defined by the axis of the Circle Cliffs Uplift. From this axis the rocks dip upstream and gently to the north, away from the river, but flatten out and reverse dip as the river approaches the broad axis of the Monument Upwarp. For about 40 river-miles the reservoir walls are again predominantly Navajo Sandstone.

The upstream limit of the Henry Basin is gradual and difficult to define but is designated at 108 river-miles above Glen Canyon Dam. Upstream from this point the Monument Upwarp has brought Paleozoic formations to river level, and the reservoir walls are composed of less permeable formations than the Navajo Sandstone (Murdock and Calder, 1969, p. 4).

Distributed between the large drape folds are numerous smaller folds which also trend generally to the northwest. They have limb dips of less than 5 to 10 degrees and may have been developed by secondary horizontal stress arising from the drape folding rather than by the primary vertical stresses that created the drape folds.

Surface faulting within the area of interest is restricted to three high-density zones: the upper reaches of Navajo Creek southeast of Page, Arizona; the area south of the San Juan arm of Lake Powell, northeast of Navajo Mountain; and the area surrounding and to the immediate north of the Henry Mountains.

Igneous activity was restricted to the Henry Mountains and Navajo Mountain, which are structural domes similar in form and composition to many of the domes scattered throughout the central Colorado Plateau (Nelson, 1975, p. 55-58).

Fracture Study

At the beginning of this bank storage study we postulated that fracture permeability could play a significant role in the movement of water into bank storage. Therefore, our efforts were directed toward an evaluation of the fracture systems in the lake vicinity.

Large-scale, regional fracture systems which are unrelated to local structure are common throughout this portion of the Colorado Plateau. Many of these fractures persist in highly oriented zones up to 20 miles (30 kilometers) long. The regional fractures in the Lake Powell area are extension fractures and because displacements are perpendicular to the fracture plane no gouge is developed. Therefore, in principle the regional fractures could act as good subsurface conduits for water.

Ground and air-photo fracture measurements indicate that water loss along regional fractures is probably small because the consistent trend in the immediate vicinity of

Lake Powell is 20 degrees either side of the east-northeast direction (north 50 to 60 degrees east). This is roughly parallel to the main Colorado arm of the lake throughout its length (major bays excluded). Thus regional fractures can only aid in water loss parallel to and downstream from the lake. However, because the impermeable Triassic Chinle Formation is folded to form a flow barrier on the northeast flank of the Echo Cliffs Monocline (which bounds the southwestern, downstream end of Lake Powell), and because no discernible increase in water seepage has been noted in the canyon walls below Lake Powell and Echo Cliffs, we conclude that regional fractures do not facilitate the high water losses from the reservoir (Nelson, 1975, p. 130).

Shear fractures in the Mesozoic formations of southeasttern Utah tend to be filled with a fine-grained calcite or quartz-cemented gouge material. Often in the Lake Powell area, particularly in the Navajo Sandstone, this gouge (because of its low porosity and permeability) acts as a fluid-flow barrier in the subsurface. Thus is makes shear fractures unlikely as conduits for water loss from Lake Powell.

Data from two isolated wells in two of the most highly fractured zones at Lake Powell--both less than 0.5 mile (0.8 kilometer) from the lake--produced such small flows from fractured formations as to further indicate that fractures play a very little role in water loss (Nelson, 1975, p. 132).

Theoretical estimates tend to substantiate the conclusion that fracture permeability is very subordinate to whole-rock or matrix permeability in the Lake Powell area. Parsons (1966) presented equations which describe the total fluid flow in a fractured rock system:

$$K_{fr} = K_r + \frac{e^3 \cos^2 a}{12D}$$

$$K_f = \frac{e^2}{12}$$

where K_{fr} = permeability of the fracture plus rock system

K_f = permeability due to the fracture

K_r = permeability of the intact rock

e = width of the fracture opening

D = average spacing of fractures

a = angle between the axis of the pressure gradient and the fracture plane

Nelson's study (1975, p. 8) considered subsurface flow at depths of 0 to 21,000 feet (0 to 6900 meters). Determinations of the total permeability were made at six different confining pressures from 1 to 690 bars. Experiments were run at 20°, 50°, and 100°C to test the effect of temperature.

According to Nelson (1975, p. 133):

> "In applying this equation to the Lake Powell Area in general, further assumptions can be made to maximize total subsurface fluid flows and to show that even under the most favorable conditions for fracture-flow only a small contribution is made to the total regional permeability. First, the angle between the pressure gradient and the fracture plane (a) is taken as zero, maximizing $\cos^2 a$ at 1. This means that all fractures are perpendicular to the shoreline. Secondly, experimental values of whole-rock permeability (k_r) and fracture width (e) at atmospheric confining pressure for Navajo Sandstone maximize subsurface permeabilities since no decrease due to compression of fractures with depth is allowed.

Thirdly, an average value for fracture density (D) taken from comprehensive field measurements on the Navajo Sandstone gives a characteristic fracture flow for the area as a whole.

"Using average figures for k_r, e, and D from the experimental and field measurements, one calculates fracture and total system permeabilities for the maximized conditions. The results show that the flows due to fractures are negligible compared to whole-rock flows. The results shown [in Figure 19] demonstrate the relations between the percentage of total permeability due to fractures, D, and depth of burial."

Subsurface flow approximations from the Navajo Sandstone, the formation comprising 40 percent of the shoreline of Lake Powell and over 80 percent of the total aquifer volume available to bank storage, show that fractures contribute only about 2.3 percent of the total permeability of the system (Nelson, 1975, p. 136).

Nelson (1975, p. 49), after extensive laboratory testing of Navajo Sandstone, made the following conclusions:

- Fractures are closed to fluid flow at lower effective pressures than is the whole-rock permeability

- Deformation of fractures under confining pressure is mostly nonelastic, while that of the whole rock is substantially elastic

- It is difficult to distinguish the difference between k_f and k_r on rate of change of permeability in the temperature experiments

- Fractures effectively close off when k_f approaches k_r under any conditions

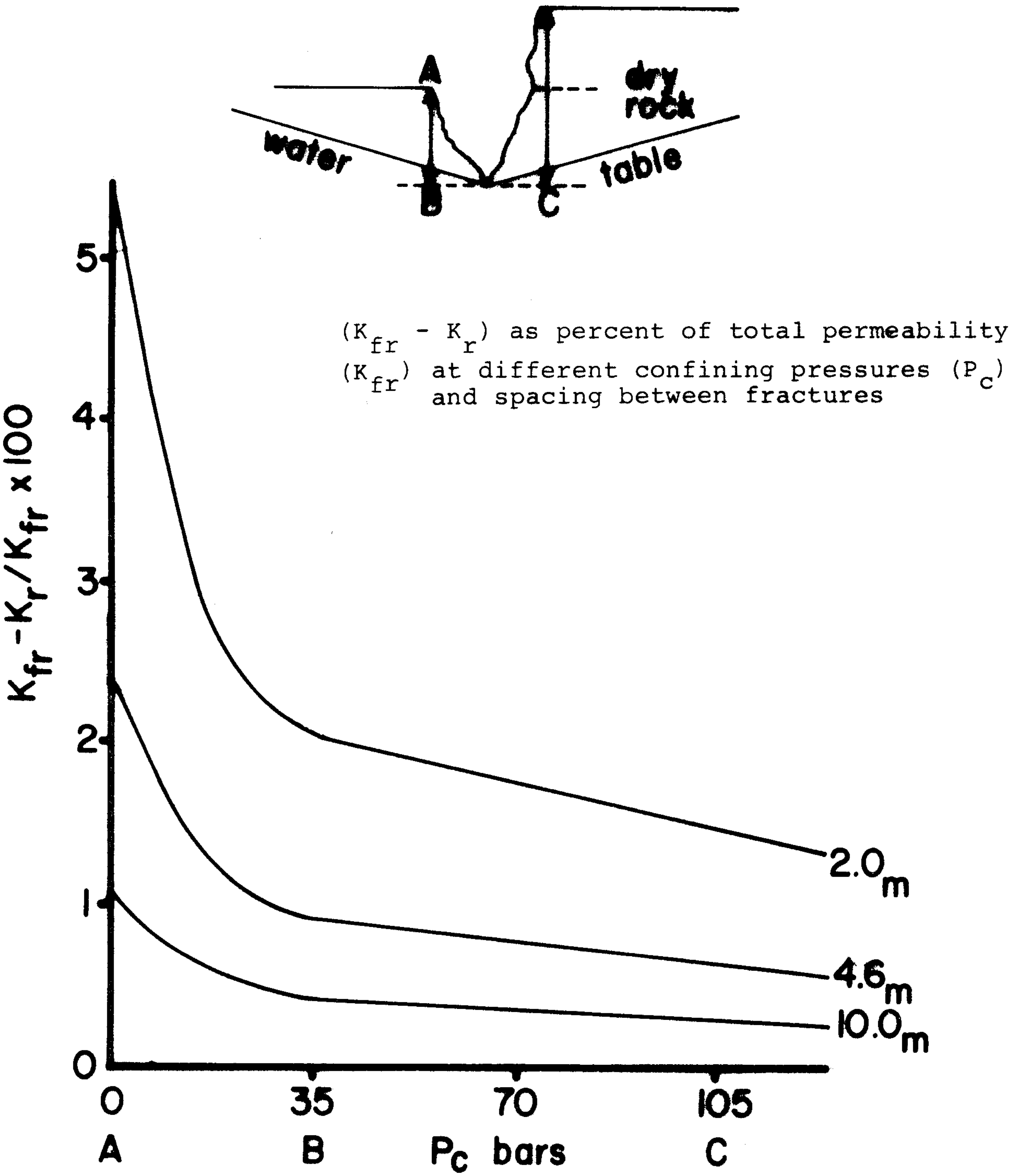


Figure 19: Graph Showing Fracture Permeability of Navajo Sandstone

- For the conditions of this study, the change in the permeability of sandstone with depth is substantially permanent when pressure is applied, but temporary when elevated temperature is applied

- Above the simulated depth of burial, both confining pressure and temperature decrease the initial values of k_r and k_f; if these effects are assumed to be additive, fracture permeability would approach zero at a depth of about 11,000 feet (3660 meters) for the Navajo Sandstone

- The change in k_f with depth of burial depends greatly on the macroscopic ductility and previous maximum depth of burial of the host sandstone

In summary, detailed fracture mapping around Lake Powell noting width, orientation, and spacing, data from two test wells in highly fractured zones, and theoretical analyses all lead to the conclusion that the role of fracture porosity and permeability is low to almost negligible in comparison to whole-rock porosity and permeability at Lake Powell.

Hydrology of Bank Storage

The Lake Powell reservoir lies in an area where there has been little in the way of municipal or other water-supply development from ground water. Therefore, there are not very many wells in close proximity to the lake.

Before Glen Canyon Dam was built, the Colorado River ran through a deep canyon. The sparse data on the water table in the areas along this canyon indicate that the water table sloped down toward the canyon (Cooley et al., 1969).

Most of the well information was from the south side of the canyon, but the north side is probably quite similar with regard to water-table configuration. These well data indicated that the water table rose to above 3700 feet (1200 meters) in elevation--the normal maximum reservoir surface level--within less than about 5 miles (8 kilometers) from the lake. Figure 20a shows this configuration. The deep river canyon served as an outlet for ground-water flow. This flow and flow from some local perched ground water were the sources of the many springs and seeps in the so-called glens of Glen Canyon, and were responsible for the juxtaposition of moist, verdant glens in such an arid environment. As the reservoir filled, the increase in elevation, or head, of the water in the canyon changed the former ground-water outlet into a source. Water then flowed from the reservoir out into the rock formations lining the shore. Initially, bank storage filled the zone ABC shown in Figure 20b. This is the primary zone of bank storage with which this study is concerned.

There is now no outlet for the ground-water flow nor the bank storage flow. Thus, the area ACE (Figure 20c) will eventually fill. The subarea of ACD will slowly fill with reservoir water and ground water; subarea CDE will fill slowly with ground water. It is likely that the shaded zone in Figure 20c will take decades to fill, whereas the primary bank storage zone in Figure 20b has a response time of only a few years.

As previously mentioned, the Navajo Sandstone is the most important formation with regard to bank storage at Lake

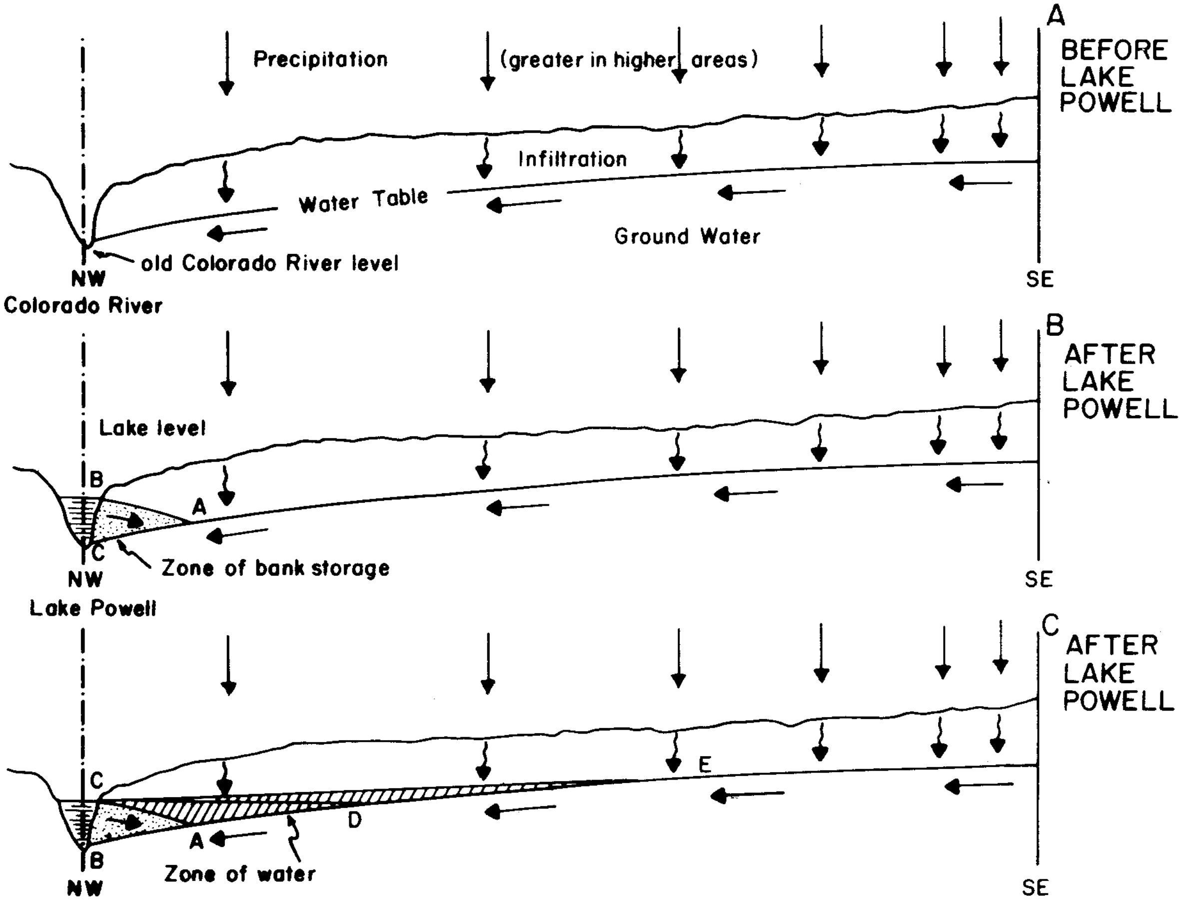


Figure 20: Generalized Profiles of Bank Storage Configuration at Lake Powell

Powell. It comprises over 80 percent of the total near-lake volume of rock that can be filled with bank storage waters. Originally it was thought that fracture permeability could play a major role in the bank storage situation. However, as discussed previously, the fractures (although impressive in outcrop and from air photographs) are at any depth generally too widely spaced to play a major role in the bank storage situation. Other formations in the more northern regions are believed to play a larger role than originally may have been thought. The most important of these formations were considered to be the Wingate Sandstone, and, in the extreme northern portion of the lake, the White Rim Sandstone, although this latter formation comprises the shoreline in a relatively small portion of the northern end of the reservoir.

Test Wells

Two exploratory wells were drilled to examine certain crucial areas on the northern side of the lake. One well was drilled in what was believed to be a highly fractured zone of the Navajo Sandstone. This well did indeed intersect fractures in the Navajo Sandstone. However, results of a pumping test of this well revealed that the real permeability in this area was very low. The rate of infiltration into bank storage in this zone would be very close to the rate of infiltration due to bulk or whole-rock permeability, with fractures playing little or no role in the hydrologic picture at this well site. The drilling and testing of this well and the data derived converged with the data derived from fracture analysis in the area. The results indicate that fracture permeability plays little or no role in the bank storage situation and that whole-rock permeability is the major factor at Lake Powell.

A second test well was drilled at the extreme northern end of the lake, again on the northern side. This well was drilled in the Organ Rock-Moenkopi Formations and penetrated down to and into the White Rim Sandstone. In the Organ Rock-Moenkopi sequence the permeability was effectively negligible. These formations, although appearing highly fractured in outcrop, evidently with any depth of overburden (on the order of 100 feet or more) appear to be healed, with their permeabilities correspondingly quite low. This was expected from the petrology of these formations due to their high clay and silt content. Upon penetration of the White Rim Sandstone, there was a tremendous upsurge of water in this well and the pumping test revealed that the permeability of the upper portion of the White Rim Sandstone was extremely high. However, the water that entered the well, which was chemically analyzed, appeared to be very different from the lake water, although the well was only a few hundred feet from the lake. Therefore, it was apparent that at this time there had been little penetration of lake water into this zone. Subsequent to the pump test and chemical analysis of the water from this well, it was apparent that the hydrologic head in the well did respond to lake level, although there did not appear to be any physical movement of lake water into the zone of the well. This is understandable in that pressure effects will be seen very quickly in aquifers at some distance. However, the physical movement of water from one location to another may be much slower.

These two strategic data points on the north side of the lake helped fill in the general picture of the hydrology of ground water in the vicinity of Lake Powell, because their locations tested ground-water conditions near adjacent basin areas.

Regional permeability trends must be considered if water is in fact leaving the immediate area of the lake into surrounding structural basins. According to Nelson (1975, p. 141),

> "Two primary factors must be considered; geographic trends in permeability, and permeability changes related to sedimentary structures. Jobin (1962) presents isopachous isopermeability and isotransmissivity maps for all the relevant rock formations in the Lake Powell Area. The Navajo Sandstone isopermeability map indicates a strong increase in permeability from east to west across the Plateau. Other aquifers like the Entrada, Kayenta and Cedar Mesa Sandstones either have very complex trends or are concentric about the center of the Plateau. Pertinent to the water-loss problem is the Navajo pattern because of its relatively high permeability with respect to the other formations in the area and because its trend across the area is the most important with respect to water movement away from the Lake. This pattern indicates that subsurface flow rates would be much faster perpendicular to the trend of Lake Powell...The most important and permanent sedimentary structure in the Navajo Sandstone is cross-bedding. Data have been published on its directional permeabilities parallel and perpendicular to cross-bedding (Bureau of Reclamation, 1957). Horizontal permeability is a factor of 2 greater than the vertical. The reason for the importance of this fact is that cross-bedding is most often inclined to the horizontal, and this will cause a statistically lower horizontal permeability in the N 43 W direction than in any other. It is possible that the overall trend in regional permeability can be nullified by the cross-bedding effect."

The transmissivity coefficients as derived by Jobin (1962) and Ritzma and Doelling (1969, Table 5) indicate the relatively higher transmissivity of the Navajo Sandstone and the much lower transmissivity of the Wingate Sandstone, Entrada Sandstone, and Kayenta Formation.

Transmissivity in the Cutler Group is variable among its formations and outcrop localities within each formation as indicated in Table 3. The Carmel, Chinle, and Moenkopi Formations exhibit low transmissivity. The Chinle Formation underlies the downstream two-thirds of the reservoir as well as much of the San Juan arm. The combination of very low transmissivity and occurrence in a structural and hydrologic basin enclosing much of the reservoir permits the Chinle Formation to act as a "seal" enclosing the downstream portions of the reservoir (Murdock and Calder, 1969, p. 4). The existence of this seal and high water table around the lake combine to place limits on the total amount of potential bank storage at Lake Powell.

The conclusions resulting from considerations of the geology, the structure, and the hydrology of bank storage around the lake are that there are definite limitations upon how much water enters bank storage near the lake.

As previously mentioned, the only way to make estimates of bank storage is to construct a model of Lake Powell that considers the other major components of the water budget. The geologic and hydrologic studies have, however, helped to place limits on the hydrologic system and have allowed reduction of certain pre-lake estimates of bank storage to a better-defined level.

Table 3: Transmissivity of Geologic Formations at Lake Powell

Hydrologic Unit	Transmissivity Relative to the Mean (X)[a]	Transmissivity[b]
Entrada Sandstone	0.4	3.2
Carmel Formation	0.1	0
Navajo Sandstone	7.0	6.1
Kayenta Formation	0.1	2.1
Wingate Sandstone	0.5	3.6
Chinle Formation	0.1	0
Moenkopi Formation	0.1	0
Cutler Group	0.1	1-4

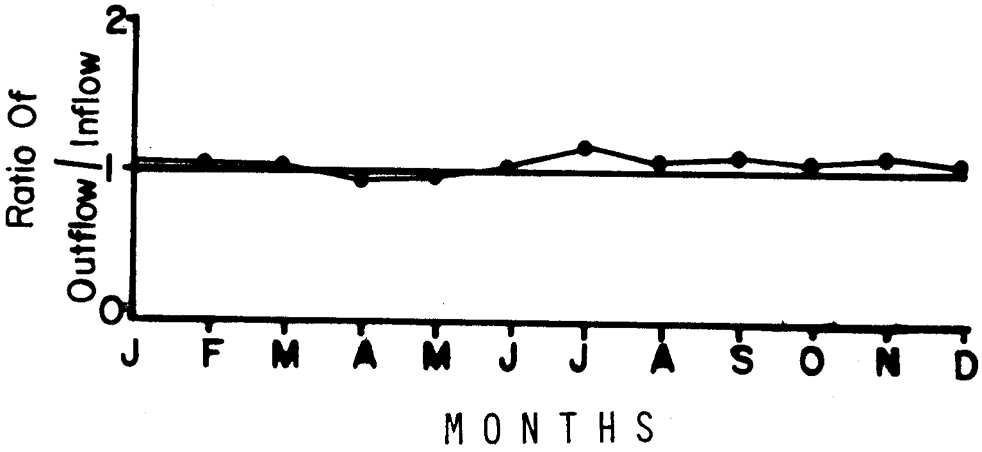
a = mean transmissivity of all hydrologic units on the Colorado Plateau measured in this study (Jobin, 1962, p. 103). Transmissivity is expressed quantitatively by the coefficient of transmissivity which is defined as the product of mean permeability and total thickness of the transmitting medium expressed in units of darcy-feet (Jobin, 1962, p. 6).

b = Transmissivity value is the natural logarithm of the product of the arithmetic mean thickness in feet and arithmetic mean permeability in darcys (Ritzma and Doelling, 1969, p. 42).

[Editor's Note: A darcy is a standard unit of permeability. One darcy is equivalent to the passage of 1 cc of fluid of 1 centipoise viscosity flowing in 1 second under a pressure differential of 1 atmosphere through a porous medium having an area of cross-section of 1 cm^2 and a length of 1 cm.]

RESERVOIR MODEL

In order to model the Lake Powell reservoir we determined the regime of this section of the Colorado River prior to the creation of the lake by regression analysis of inflow versus outflow at that time. Gauges were installed on the three major rivers flowing into the lake during the early 1920s. By the beginning of calendar year 1927, these modern recording gauges had been installed at the three major inflow sites and at the outflow site at Lees Ferry. The regression analysis was performed using the outflow at Lees Ferry as the dependent variable and the sum of the three inflows as the independent variable. This was done on a monthly basis in order to model the monthly effects on Lake Powell. The correlation coefficients and the explanation of variance were extremely high, as might be expected, since the gauged inflow areas represent the major portion of the area of the UCRB. The outflow exceeds the inflow on an annual basis, and for most of the individual months, as a result of small amounts of both tributary inflow from ungauged areas and groundwater inflow into the canyon. For the months of April and May the inflow exceeds the outflow (Figure 21). April and May are the months when the spring runoff usually flows into this area from the mountains to the east and north of Lake Powell. During this rising flood wave of spring runoff, water went into bank storage even during the time when only the river was there. Thus there was a small amount of bank storage effect in the canyon even prior to the creation of Lake Powell. The regression analysis showed that it was possible to calculate fairly accurately what the outflow would be using the inflow data from the three major rivers. This allows us to calculate what the outflow would be after



	Mean Inflow	Mean Outflow	Outflow/Inflow
J	305,160	322,630	1.0572
F	349,770	372,220	1.0642
M	552,520	561,940	1.0170
A	1,215,160	1,156,190	.9515
M	2,669,720	2,617,250	.9803
J	2,880,860	3,035,130	1.0535
J	1,102,380	1,273,580	1.1553
A	573,720	630,250	1.0985
S	434,080	481,000	1.1081
O	465,470	503,000	1.0806
N	397,520	438,830	1.1039
D	326,860	356,080	1.0894

Figure 21: Ratio of Outflow to Inflow of Water for Glen Canyon Prior to the Creation of Lake Powell, Based on Flow Data for 1927 through 1962

the creation of the lake in response to the inflow from the three major rivers.

Against this predicted outflow can be compared the change in volume of surface storage in the reservoir, the evaporation calculations, and the precipitation input that is now salvaged by falling directly onto the lake surface. This is the precipitation that would have fallen on the river and on the hillside as described earlier. The precipitation on the hillside which would have been lost prior to the creation of Lake Powell is now salvaged by the water falling directly into the lake. After all of these various quantities in the water budget are measured or calculated, the residual water unaccounted for is presumed to be in bank storage.

The model was constructed to recreate the hydrology of Lake Powell from 1963, when the reservoir started filling, to the end of 1976. It is based on calendar-years because we feel they are more appropriate for this type of model in this area than is the standard water-year used by the USGS. The inflow to the lake is determined by the sum of data from the three gaging stations and the coefficient and intercept determined by the regression analysis. This is the water that would appear at Lees Ferry if the lake were not there. This figure was calculated each month for the entire period of the model.

The amount of precipitation is a relatively minor quantity in the model; however, we felt that it should be included because there are reasonably accurate estimates of precipitation for the lake, and the creation of the lake, as previously stated, does salvage some of the precipitation which otherwise would have been lost. For 1969 through 1976 there is measured precipitation data in the hydrometeorological data sheets available from the Bureau of Reclamation. During the evaporation study rain gauges were installed on the individual rafts on the lake. The precipitation data were compared with the land-based data measured by the Bureau of Reclamation. The data used were from the land-based station in that they were summed for each individual month, whereas the measured data on the lake itself were measured at irregular intervals and did not coincide with end-of-month values. The lake precipitation data were plotted and compared with the land-based measurements and there was no appreciable difference between them. Although they did vary from spot to spot and from storm to storm, the general cumulative totals were very similar.

Therefore the total inflow of the model was the inflow data from the three major gaging stations adjusted by regression analysis, plus the precipitation input multiplied by the lake surface averaged for that particular month. The outflow of the model was the outflow data at Lees Ferry as measured by the USGS. The volume change is determined from changes in lake level and from the elevation-capacity tables.

The evaporation loss was calculated for 1974 by using the data collected from the raft stations. The evaporation for 1973 from June through December was also based upon raft data. The evaporation for January through May of 1973 and all other years except 1976 was based upon pan-evaporation data from the Wahweap pan multiplied by the pan coefficients as determined from the 1973 and 1974 data showing the relationship between pan evaporation and evaporation as calculated at the lake. For 1976, since the pan data were not available when this Bulletin was prepared, the evaporation figure was estimated to be the average evaporation for the 14 years of record.

The equation below shows how the residual was calculated based on the other quantities of the water budget. The model is set to calculate bank storage for individual months and also a cumulative bank storage which summed the bank storage during the entire 14 years covered by the model.

Inflow + Precipitation Input - Outflow
- Volume Change - Evaporation = Bank Storage

Inflow = (Green River + Colorado River + San Juan
River) K + Intercept

where Precipitation Input = precipitation x average lake area
Outflow = Lees Ferry gauge data
Volume Change = change in surface content from lake level
Evaporation = evaporation rate x average lake area for month
Bank Storage = residual from water-budget equation
K = regression coefficient

The lake was filling during most of this period. Therefore bank storage is almost always a positive figure. There were a few occasions when the lake level dropped and the bank storage for a particular month was negative, indicating that water flowing out from bank storage entered the reservoir. The largest negative figures occurred in 1973 when the lake level was lowered appreciably as a result of a court decision relating to the Rainbow Bridge controversy. During this period of time when the lake level dropped, there was significant return flow from bank storage. When the lake elevation, volume change, and bank storage figures are compared, it appears that there is often a lag of about a month in the response. With a drop in water level or a decrease in lake volume, the return from bank storage may not appear in the data for that particular month, but will appear in the following month's data. This is understandable in that there would be a delay, once the water-table gradient was changed and the flow shifted from one direction to the other, for a substantial quantity of water to move either into bank storage or out of bank storage. In some months there is a very small amount of water shown as a negative value. Because the inflow, outflow, and evaporation have intrinsic errors in determination, the bank storage on these very low values is probably at the noise level and no great significance should be attached to these small negative or positive numbers in bank storage. The bank storage estimates are probably all plus or minus 10,000 acre-feet and only changes above that amount should be regarded as indicative of real change.

The model was started at the end of June 1963, at which time there was 2,008,000 acre-feet of water in the reservoir. Of this amount, 1,998,000 acre-feet was classified as dead storage (or water that cannot be released from the reservoir). The surface elevation reached 3370.5 feet (1105.8 meters). The tables used in the model for volume and surface area, as a function of surface elevation, start at 3370 feet (Bureau of Reclamation, 1966). Therefore, although the reservoir started filling months earlier, the data set for the model could go back only to the end of June, and calculated bank storage at that time was 195,213 acre-feet. The results of the model are in Appendix C.

In the plot of bank storage (Figure 22) it is evident that after a significant rise in lake level stabilizes for a year or more the rate at which water enters bank storage declines appreciably. This indicates that the area near the lake has become saturated, the gradient has lessened, and the flow of water has appreciably slowed because of the decrease in gradient and the saturation of the rocks near the lake area.

The model, run until the end of 1976, indicates that there is probably about 8 million acre-feet of water in bank storage. The cumulative figure may be more accurate than those from the individual months in that this quantity integrates small positive or negative errors in the various quantities used in the water budget. Assuming that these errors are somewhat compensating over time, the cumulative effect will integrate in a manner such that the positive and negative noise seen in the monthly data is a lesser effect in the long-term cumulative bank storage.

Although it is difficult at this time to determine accurately the availability of water in bank storage, the months in early 1973 did show that there was appreciable return flow from bank storage, and that during the months that the lake surface was dropped there was a return flow of approximately 300,000 acre-feet as a result of this lowering of the lake surface. This is an indication that bank storage is indeed a storage phenomenon. It is not water totally lost for future use, however the full evaluation of its recoverability may have to wait until the reservoir has been operating for several more years. Although this model is rather simplistic, it produces a good first approximation of the water budget at Lake Powell. As data are collected

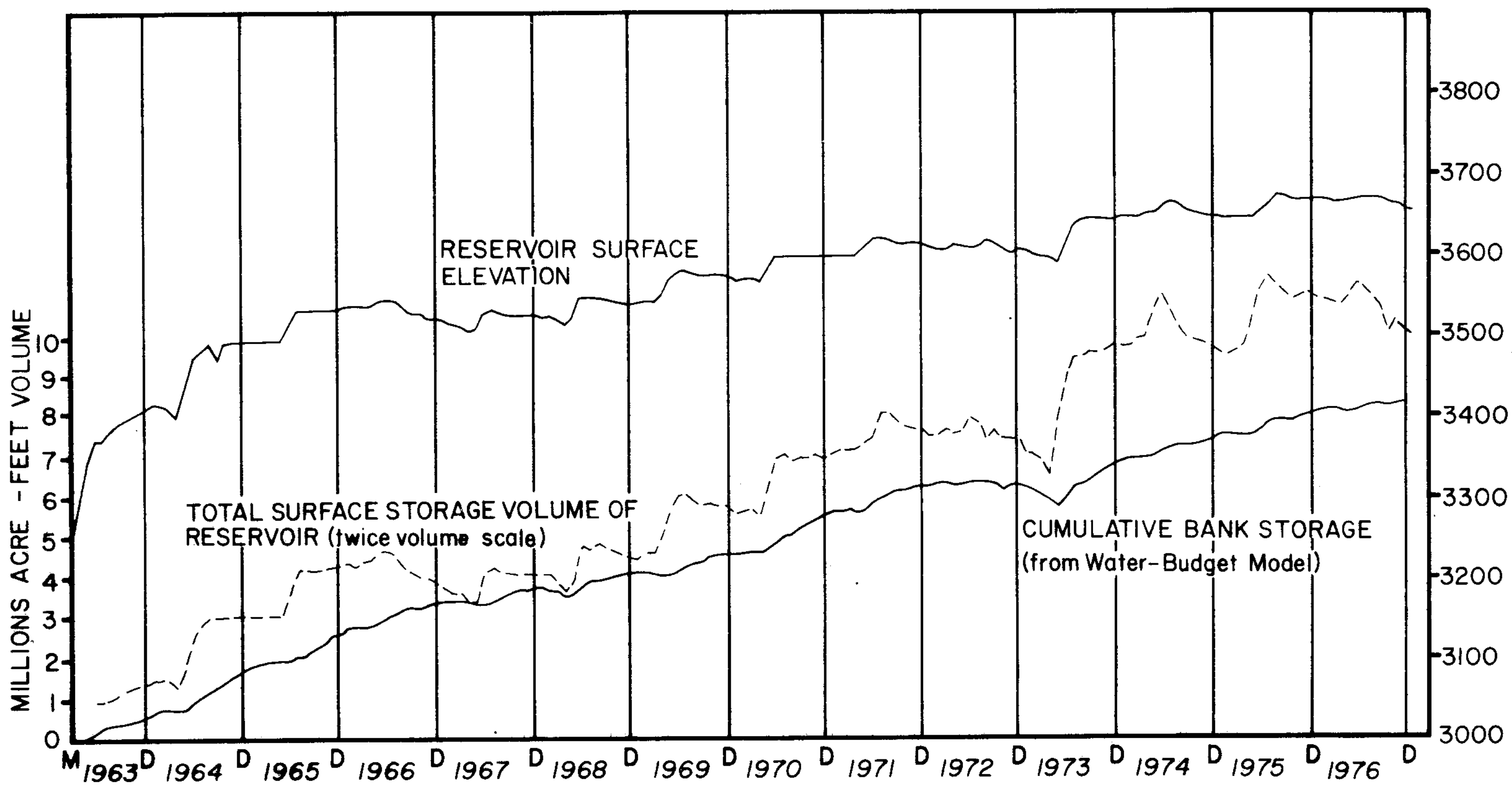


Figure 22: Comparison Between Bank Storage as Estimated by the Water-Budget Model and Water-Surface Elevation

in the future, they can be easily placed in this model to continue to monitor the effects of Lake Powell on the Colorado River system.

The cumulative bank storage has also been compared to water levels in wells near the south end of the lake. This analysis indicates that certain of these wells are indeed good indices for bank storage at Lake Powell and they can also be used to monitor bank storage at the lake.

CONCLUSION

The creation of the Lake Powell reservoir behind Glen Canyon Dam caused a large perturbation of the flow of the Colorado River. The reservoir has increased the availability of water for use in the UCRB, but due to evaporation loss and bank storage the total supply has been diminished. This type of diminishment is common to most reservoirs, especially in semi-arid areas such as the Lake Powell region.

Extensive analyses of evaporation, as have been described in this Bulletin, indicate an annual evaporation rate at Lake Powell of about 70 inches (178 cm), and a probable average net evaporation loss of 500,000 acre-feet per year, due to the creation of the reservoir.

Bank storage, or water seeping into the rock formations around the lake, totalled about 8.5 million acre-feet at the end of 1976, for an average seepage rate of 607,000 acre-feet per year for the first 14 years of the reservoir's operation. As the reservoir level stabilizes, the rate of water entering bank storage decreases, although the total amount still increases. When the water level drops there is appreciable return flow back into the reservoir. The actual proportion of returnable bank storage is difficult to estimate from the model period because the reservoir was primarily filling during this period.

There was a substantial environmental cost incurred in the creation of Lake Powell. However, many individuals feel that there is a gain in access to scenic areas and still-water recreation. The environmental gains and losses are difficult to quantify, and a positive or negative conclusion is therefore subjective.

The gain in control over the surface-water resources of the UCRB is offset by reservoir losses at Lake Powell. This Bulletin has attempted to quantify these losses so that water-resource administrators and decision-makers will be able to make objective judgments about the value and management of large reservoirs of this type.

ACKNOWLEDGMENTS

The following institutions and individuals assisted in the research for this Bulletin. This does not imply approval or endorsement of the findings and conclusions.

Museum of Northern Arizona, Flagstaff, Arizona
Lowell Observatory, Flagstaff, Arizona
Texas A&M University
U.S. Bureau of Reclamation
U.S. National Park Service

Karen Antlitz, manuscript preparation
Edward R. Cook, programming, water-budget model
Robert Cudney, electronic and field assistance
Paul Lindberg, programming and data reduction
Steven Spydell, field assistance and data reduction
Ann K. Stern, manuscript preparation
Jeni M. Varady, editor
Mary S. Wolters, drafting
John Zweizig, programming

The research was funded by the Research Applied to National Needs (RANN) Program of the National Science Foundation through Grants GI-34840, AEN 72-03470, and AEN 76-16691.

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GLOSSARY

active storage	water storage in a reservoir that can be released during reservoir operation
aeolian	wind-transported or wind-deposited
aquifer	a body of rock that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of ground water to wells and springs
calcareous	containing calcite, calcium carbonate
consumptive use	water used so that it is not returned to the system, often a river, from which it was taken
cross-bedded	having beds or layers that are at an angle to the larger layers enclosing them
dead storage	water storage in a reservoir that cannot be released
evaporation pan (Class A)	an open-topped tank from which water can evaporate; the water temperature, wind, and amount of water evaporated are measured; Class A means the installation meets National Weather Service standards
fluvial	from or pertaining to rivers
friable	easily crumbled
geosyncline	a trough in the earth's crust where sediments collect from surrounding higher source areas
gouge	fine-grained material formed by two sides of a rock fracture or fault moving against each other

igneous	formed by volcanic activity
isopachous	showing areas of equal thickness of geologic formations
isopermeability	showing areas of equal permeability of geologic formations
isotransmissivity	showing areas of equal transmissivity of geologic formations
lacustrine	from or pertaining to lakes
marine	oceanic
pan-to-lake coefficients	ratio between evaporation rate at a pan station and a lake

APPENDIX A: RAFT EVAPORATION IN INCHES (1973)

Day		Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
131	#	0.1466			
132	#	0.1619			
133	#	0.1517			
134	#	0.1280			
135	#	0.1191			
136	#	0.1392			
137	#	0.1736			
138	#	0.1825			
139	#	0.1875			
140	#	0.1524			
141	#	0.1720			
142	#	0.1885			
143	#	0.2123			
144	#	0.2436			
145	#	0.2427			
146	#	0.2163			
147	#	0.2193			
148	@	0.2144			
149		0.2009			
150		0.1380			
151		0.2414			
152		0.2170			
153		0.2121			
154		0.2594			
155		0.1993			
156		0.1330			
157		0.1767			
158		0.1633			
159		0.1287			
160		0.1245			
161		0.1603			
162		0.2556			
163		0.3070			
164		0.2243			
165		0.2444			
166		0.3465			
167		0.3695			
168		0.2108			
169		0.3163			
170		0.3953			
171		0.2347			
172		0.2904			
173	@	0.2392			
174	*	0.1609	0.1400		
175	*	0.1623	0.1412		
176	*	0.2701	0.2350		
177	*	0.1498	0.1303		
178	*	0.2011	0.1750		
179	*	0.3032	0.2638		
180	*	0.3464	0.3014		

Appendix A (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
181	* 0.2887	0.2512		
182	* 0.3054	0.2657		
183	* 0.2547	0.2216		
184	* 0.1871	0.1628		
185	* 0.2708	0.2356		
186	* 0.1925	0.1675		
187	* 0.3295	0.2867		
188	* 0.3380	0.2941		
189	* 0.2895	0.2519		
190	* 0.1903	0.1656		
191	0.2099	0.1805		
192	0.2370	0.2439		
193	0.2784	0.3295		
194	0.3135	0.2561		
195	0.2335	0.3260		
196	0.3140	0.2717		
197	0.3367	0.3661		
198	0.2152	0.3610		
199	0.3470	@ 0.2802		
200	0.2999	@ 0.2802		
201	0.2597	0.2644		
202	0.2365	0.2166		
203	0.3230	0.3515		
204	0.2749	0.1990		
205	0.2587	0.1903		
206	0.1972	0.2472		
207	0.2834	0.2856		
208	0.3300	0.2961		
209	0.3113	0.2475		
210	0.2952	0.2698		
211	0.2589	0.2253		
212	0.2607	0.2437		
213	0.1831	0.2020		
214	0.2290	0.2388		
215	0.3688	0.3354		
216	0.3681	0.3044		
217	0.2468	0.2703		
218	0.3566	0.3463		
219	0.2582	0.3163		
220	0.2788	0.2331		
221	0.2218	0.1752		
222	0.3768	0.2945		
223	0.3611	0.3177		
224	0.2762	0.2252		
225	0.2720	0.2549		
226	0.3018	0.2994		
227	0.2745	0.2374		
228	@ 0.2662	0.2891		
229	@ 0.2662	0.3160		
230	0.1504	0.2556		
231	0.1684	* 0.2782		
232	0.2356	# 0.2161		
233	* 0.3177	# 0.2764		
234	* 0.3045	# 0.2649		
235	* 0.3487	# 0.3034		

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
236	* 0.3728	# 0.3243		
237	* 0.2724	# 0.2370		
238	* 0.2525	# 0.2197		
239	* 0.2763	# 0.2404		
240	* 0.2952	# 0.2568		
241	0.3166	# 0.2151		
242	0.2696	# 0.2143		
243	0.3178	# 0.2413		
244	0.5953	# 0.2398		
245	0.4291	# 0.2716		
246	0.2483	# 0.2512		
247	0.2097	# 0.2493		
248	0.2398	# 0.2252		
249	0.1637	# 0.2032		
250	0.2834	# 0.2465		
251	0.4598	# 0.2848		
252	0.3341	# 0.2602		
253	0.3203	# 0.2412		
254	0.1800	# 0.2220		
255	* 0.1659	# 0.1908		
256	* 0.1395	# 0.1604		
257	* 0.2204	# 0.1668		
258	* 0.2303	# 0.1743		
259	* 0.2402	# 0.1818		
260	* 0.2350	# 0.1779		
261	* 0.2426	# 0.1836		
262	* 0.3177	# 0.2405		
263	* 0.4035	# 0.3054		
264	* 0.3422	# 0.2590		
265	* 0.3648	# 0.2761		
266	* 0.3702	# 0.2802		
267	* 0.3999	# 0.3027		
268	* 0.3588	# 0.2716		
269	# 0.2772	# 0.2166		
270	# 0.2838			
271	# 0.2750			
272	# 0.2474			
273	# 0.2479			
274	# 0.2515			
275	# 0.2594			
276	# 0.1738			
277	# 0.4018			
278	# 0.3758			
279	# 0.3897			
280	# 0.4101			
281	# 0.3805			
282	# 0.3601	# 0.2643		
283	# 0.2821	# 0.2178		
284	* 0.1802	# 0.1568		
285	* 0.1806	# 0.1571		
286	* 0.1603	# 0.1395		
287	* 0.1333	# 0.1160		
288	* 0.1321	# 0.1149		
289	* 0.1338	# 0.1164		

Appendix A (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
290	0.2029	# 0.1188		
291	0.2042	# 0.1267		
292	0.2085	# 0.1271		
293	0.2093	# 0.1329		
294	0.2132	# 0.1383		
295	0.2104	# 0.1277		
296	0.2146	# 0.1538		
297	0.2382	# 0.1639		
298	0.2554	# 0.1674		
299	0.2703	# 0.1816		
300	0.2801	# 0.1918		
301	0.2741	# 0.1780		
302	0.2596	# 0.1857		
303	0.2544	# 0.1954		
304	* 0.2119	# 0.1844		
305	* 0.2142	# 0.1864		
306	* 0.2178	# 0.1895		
307	* 0.2147	# 0.1868		
308	* 0.2454	# 0.2135		
309	* 0.2396	# 0.2085		
310	* 0.2122	# 0.1846		
311	* 0.1902	# 0.1655		
312	* 0.1488	# 0.1295		
313	* 0.1169	# 0.1017		
314	* 0.1288	# 0.1121		
315	* 0.1392	# 0.1211		
316	* 0.1176	# 0.1023		
317	* 0.1364	# 0.1187		
318	* 0.1957	# 0.1703		
319	* 0.2278	# 0.1982		
320	* 0.2274	# 0.1978		
321	* 0.2191	# 0.1906		
322	* 0.1895	# 0.1649		
323	* 0.1754	# 0.1526		
324	* 0.2274	# 0.1978		
325	# 0.2078			
326	# 0.2178			
327	# 0.2279			
328	# 0.2380			
329	0.2434			
330	0.2426			
331	0.2626			
332	0.2295			
333	0.2120			
334	0.1942			
335	0.1845			
336	0.1965			
337	0.2192			
338	0.2229			
339	0.2161			
340	0.1751			
341	0.1307			

Appendix A (continued)

Day		Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
342		0.1307			
343		0.1258			
344		0.1303			
345		0.1278			
346		0.1179			
347		0.1346			
348		0.1440			
349		0.1753			
350		0.1670			
351		0.1643			
352		0.1344			
353		0.1809			
354		0.2039			
355		0.1973			
356		0.1958			
357		0.1917			
358		0.2076			
359		0.2012			
360		0.2198			
361	@	0.1897			
362	@	0.1897			
363	@	0.1897			
364	@	0.1897			
365	@	0.1897			

Calculated using one or more meteorologic parameters not measured at raft and obtained elsewhere.

@ Estimated from preceding and following days.

* Estimated from data at another raft station.

Note: 1974 values were not used to estimate the end of 1973 because equipment changes were made at the end of the year.

APPENDIX B: RAFT EVAPORATION IN INCHES (1974)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
1	@ 0.0983	* 0.0956		
2	@ 0.0983	* 0.0956		
3	@ 0.0983	* 0.0956		
4	@ 0.0983	* 0.0956		
5	@ 0.0983	* 0.0956		
6	@ 0.0983	* 0.0956		
7	@ 0.0983	* 0.0956		
8	@ 0.0983	* 0.0956		
9	@ 0.0983	* 0.0956		0.0915
10	@ 0.0983	* 0.0956		0.0689
11	# 0.1126	* 0.1096		0.0645
12	# 0.0953	* 0.0927		0.1174
13	# 0.0937	* 0.0912		0.0980
14	# 0.0950	* 0.0924		0.0997
15	# 0.0947	* 0.0921		@ 0.0835
16	# 0.1028	* 0.1000		0.0773
17	# 0.1030	* 0.1002		
18	# 0.0980	* 0.0954		
19	# 0.0981	* 0.0955		
20	# 0.0923	* 0.0898		
21	# 0.1057	* 0.1028		
22	# 0.1443	* 0.1404		
23	# 0.1177	* 0.1145		
24	# 0.1026	* 0.0998		
25	# 0.0981	* 0.0955		
26	# 0.0841	* 0.0818		
27	# 0.1079	* 0.1050		
28	# 0.0937	* 0.0912		
29	# 0.0874	* 0.0850		
30	# 0.0893	* 0.0869		
31	# 0.0939	* 0.0914		
32	# 0.0871	* 0.0847		
33	# 0.1060	* 0.1031		
34	# 0.1003	* 0.0976		
35	# 0.0978	* 0.0952		
36	# 0.1103	* 0.1073		
37	# 0.1198	* 0.1166		
38	# 0.1267	* 0.1233		
39	@ 0.1110	* 0.1080		
40	@ 0.1149	* 0.1118		
41	@ 0.1189	* 0.1157		
42	@ 0.1228	* 0.1195		
43	@ 0.1267	* 0.1233		
44	@ 0.1306	* 0.1271		
45	@ 0.1346	* 0.1310		

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
46	0.1385	*0.1348		
47	0.1424	*0.1385		
48	0.1463	*0.1423		
49	0.1503	*0.1462		
50	0.1542	*0.1500		
51	0.0867	*0.0844		
52	0.1327	*0.1291		
53	0.1676	*0.1631		
54	0.1913	*0.1861		
55	0.1925	*0.1873		
56	0.1834	*0.1784		
57	0.1722	*0.1676		
58	0.1477	*0.1437		
59	0.1372	*0.1335		
60	0.0974	*0.0948		
61	0.0942	*0.0917		
62	0.1309	*0.1274		
63	0.1434	*0.1395		
64	0.1437	*0.1398		
65	0.1127	*0.1097		
66	0.0804	*0.0782		
67	0.0618	*0.0601		
68	0.0434	*0.0422		
69	0.0613	*0.0596		
70	0.0666	*0.0648		
71	0.0763	*0.0742		
72	0.0743	*0.0723		
73	0.0889	*0.0865		
74	0.1101	*0.1071		
75	0.1029	*0.1001		
76	0.1027	*0.0999		
77	0.0857	*0.0834		
78	0.0908	*0.0883		
79	0.1319	*0.1283		
80	0.1401	*0.1363		
81	0.1179	*0.1147		
82	0.1219	*0.1186		
83	0.1268	*0.1234		
84	0.1190	*0.1158		
85	0.1029	*0.1001		
86	0.1235	*0.1202		
87	0.1217	*0.1184		
88	0.1196	0.0703		
89	0.1066	0.0883		
90	0.1569	0.1906		
91	0.1578	0.0938		*0.1588
92	0.1327	0.1953		*0.1336
93	0.1924	0.1464		*0.1937
94	0.1926	0.1555		*0.1939

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
95	# 0.1886	0.0802		*0.1898
96	# 0.1658	0.1439		*0.1669
97	# 0.1525	0.0956		*0.1535
98	# 0.1836	0.0750		*0.1848
99	# 0.1819	0.2205		*0.1831
100	# 0.1565	0.1925		*0.1575
101	# 0.1166	0.1335		*0.1174
102	# 0.1271	0.1771		0.1276
103	# 0.1531	0.1355		0.1513
104	# 0.1446	0.0888		0.0929
105	# 0.1661	0.0810		0.1058
106	# 0.1635	0.0868		0.0736
107	# 0.1480	0.0631		0.1809
108	# 0.1674	0.1251		0.1833
109	# 0.1434	0.2290		0.1079
110	# 0.1284	0.2023		0.1113
111	# 0.1245	0.1012		0.0928
112	# 0.1391	0.0798		0.1789
113	# 0.1400	0.1166		0.1854
114	# 0.1476	0.1463		0.1103
115	# 0.1323	0.1277		0.2929
116	# 0.1674	0.2572		0.1799
117	# 0.1697	0.1559		0.2308
118	# 0.1680	0.1589		0.2140
119	# 0.1715	0.1508		@ 0.2056
120	# 0.1761	0.1129		@ 0.2056
121	# 0.1665	0.1567		
122	# 0.0951	0.1598		
123	# 0.1041	0.1451		
124	# 0.1139	0.1264		
125	# 0.1128	0.1548		
126	# 0.1173	0.0982		
127	# 0.1047	0.0980		
128	# 0.1602	0.1208		
129	# 0.2397	0.2573		
130	# 0.2331	0.2529		
131	# 0.2582	0.1822		
132	# 0.2645	0.2211		
133	# 0.2378	0.2947		
134	# 0.2212	0.2587		
135	# 0.2215	0.2602		
136	# 0.2279	0.2136		
137	# 0.2015	*0.1961		
138	# 0.2415	*0.2350		
139	# 0.2507	*0.2439		
140	# 0.2332	*0.2269		
141	# 0.2490	*0.2423		
142	# 0.2047	*0.1992		
143	# 0.1282	*0.1247		
144	# 0.1017	0.1043		
145	# 0.1021	0.0885		

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
146	# 0.1024	0.1058		
147	# 0.1235	0.1652		
148	# 0.1342	0.2045		
149	# 0.1692	0.2683		
150	# 0.2255	0.1482		
151	# 0.1729	0.1646		
152	# 0.2205	0.1881		
153	# 0.1968	0.1723		
154	# 0.1759	0.1806		
155	# 0.1487	0.1876		
156	# 0.2044	0.3347		
157	# 0.2019	0.2581		
158	# 0.2093	0.3828		
159	# 0.2146	0.2781		
160	# 0.2332	0.1652		
161	# 0.2499	0.1195		
162	# 0.2282	0.1521		
163	# 0.2488	0.1258		
164	# 0.2312	* 0.2250		
165	# 0.3658	* 0.3559		
166	# 0.3586	* 0.3489		
167	# 0.3512	* 0.3417		
168	# 0.3480	* 0.3386		
169	# 0.3714	* 0.3614		
170	0.2630	* 0.2559		
171	0.3140	* 0.3055	0.2925	
172	0.2654	* 0.2582	0.2641	
173	0.2148	* 0.2090	0.2193	
174	0.2616	* 0.2545	0.3086	
175	0.2255	* 0.2194	0.2118	
176	0.2738	* 0.2664	0.2362	
177	0.3049	* 0.2967	0.4012	
178	0.2343	* 0.2280	0.2625	
179	0.2674	* 0.2602	0.2852	
180	0.2210	* 0.2150	0.2040	
181	0.3302	* 0.3213	0.2014	
182	0.4266	* 0.4151	0.4395	
183	0.3841	* 0.3737	0.4395	
184	0.2650	* 0.2578	0.1923	
185	0.1938	* 0.1886	0.1239	
186	0.2862	* 0.2785	0.2554	
187	0.2515	0.2827	0.3124	
188	0.3264	0.3231	0.3118	
189	0.2517	0.2809	0.2924	
190	0.2462	0.2359	0.2968	
191	0.3929	0.3740	0.4141	
192	0.2636	0.2740	0.3053	
193	0.2474	0.1674	0.1649	
194	0.2148	0.2392	0.2223	
195	0.2660	0.2807	0.2282	

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
196	0.1512	0.2192	0.2056	
197	0.1949	0.2662	0.2799	
198	0.1715	0.2261	0.2025	
199	0.2545	0.2842	0.2278	
200	0.1846	0.2279	0.1918	
201	0.2007	0.1788	0.1944	
202	0.2195	0.2233	0.2812	
203	0.1928	0.2287	@ 0.2176	
204	0.2213	0.2309	@ 0.2176	
205	0.2634	0.2140	0.2143	
206	0.2563	0.2282	0.2010	
207	0.2763	0.3017	0.2049	
208	0.2644	0.2790	0.2463	
209	0.2278	0.2893	0.2119	
210	0.2508	0.2046	0.1878	
211	0.3113	0.2918	0.2600	
212	0.3190	0.3037	0.2091	
213	0.2715	0.2888	0.2040	
214	0.3374	0.2726	0.2758	
215	0.2481	0.2617	0.2532	
216	0.3024	0.3188	0.2393	
217	0.2632	0.2393	0.2333	
218	0.3208	0.3066	0.2727	
219	0.3175	0.3019	0.2920	
220	0.2616	0.2261	0.3045	
221	0.3209	0.3244	0.2803	
222	0.3586	0.3073	0.2116	
223	0.3237	0.2723	0.2443	
224	0.3164	0.2634	0.2738	
225	0.3245	0.3372	0.3531	
226	0.2998	0.3271	0.2886	
227	0.2623	0.2677	0.2293	
228	0.2810	0.1991	0.2388	
229	0.2576	0.2027	0.2170	
230	0.3161	0.3078	0.2467	
231	0.4538	0.4632	0.3639	
232	0.3684	0.3514	0.3307	
233	0.3194	0.2413	0.2456	
234	0.2484	0.1993	0.1682	
235	0.2192	0.1920	0.1679	
236	0.2469	0.1975	0.1914	
237	0.2041	0.2072	0.1857	
238	0.1937	0.1940	0.1781	
239	0.2200	0.1990	0.1763	
240	0.2094	0.2433	0.2183	
241	0.3252	0.2405	0.1706	
242	0.3552	0.2665	0.2660	
243	0.3636	0.3390	@ 0.2019	
244	0.4452	0.4382	@ 0.1899	@ 0.2241
245	0.2357	0.2243	@ 0.1779	@ 0.2241

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay ·(1)	Hite (3)
246	0.3022	0.2482	0.1739	0.2241
247	0.3084	0.2364	0.1818	0.2241
248	0.2934	0.2765		0.2241
249	*0.2434	0.2368		0.1990
250	*0.1722	0.1675		0.1792
251	*0.1509	0.1468		0.1911
252	*0.1853	0.1803		0.2058
253	*0.2788	0.2713		0.3452
254	*0.4292	0.4176		0.5590
255	*0.3709	0.3609		0.4120
256	*0.3811	0.3708		0.4514
257	*0.3829	0.3725		0.3488
258	*0.3135	0.3050		0.2819
259	*0.2908	0.2829		0.2595
260	*0.3527	0.3432		0.2334
261	*0.2131	0.2073		0.1863
262	*0.2172	0.2113		0.2072
263	*0.1710	0.1664		0.1676
264	*0.1892	0.1841		0.1939
265	*0.2399	0.2334		0.2238
266	*0.1694	0.1648		0.2204
267	*0.1596	0.1553		0.1751
268	*0.2531	0.2463		0.2351
269	*0.2139	0.2081		0.2245
270	*0.3965	0.3858		0.4198
271	*0.2843	0.2766		0.2497
272	*0.2329	0.2266		0.1764
273	*0.1901	0.1850		0.1559
274	*0.1744	0.1697	@ 0.1581	0.1444
275	*0.1463	0.1423	@ 0.1581	0.1683
276	*0.2092	0.2035	@ 0.1581	@ 0.1789
277	*0.2074	0.2018	0.1161	@ 0.1824
278	0.2008	0.1540	0.1788	@ 0.1858
279	0.2209	0.1991	0.2086	@ 0.1893
280	0.1503	0.1622	0.1555	@ 0.1928
281	0.1462	0.1714	0.1316	@ 0.1962
282	0.1412	0.1423	0.1134	@ 0.1997
283	0.1932	0.1280	0.1353	0.1736
284	0.2915	0.2214	0.2202	0.2125
285	0.2189	0.2380	0.2426	0.2463
286	0.1910	0.1708	0.1480	0.1952
287	0.1285	0.1839	0.1376	0.1707
288	0.1087	0.1703	0.1418	0.1481
289	0.1082	0.1657	0.1289	0.1208
290	0.0696	0.1487	0.1219	0.1268
291	0.0658	0.1237	0.1049	0.1014
292	0.1179	0.1245	0.1137	0.1516
293	0.1324	0.1370	0.1194	0.1531
294	0.2098	0.2281	0.2309	0.2501
295	0.1708	0.1950	0.2047	0.1491

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
296	0.1184	0.1807	0.1136	0.1302
297	0.1422	0.1534	0.1199	0.1583
298	0.1701	0.1575	0.1290	0.2286
299	0.1920	0.1982	0.1464	0.1791
300	0.1806	0.1520	0.1141	0.1316
301	0.1962	0.3442	0.1860	0.1880
302	0.2590	0.2829	0.2553	0.2101
303	0.1739	0.1918	0.2277	0.2559
304	0.2302	0.2278	0.2459	0.2787
305	0.1424	0.1624	0.1712	0.1942
306	0.2255	0.2265	0.1746	0.1592
307	0.1839	0.1662	0.1469	0.1246
308	0.2031	0.1659	0.1259	0.1258
309	0.1972	0.1723	0.1368	0.1689
310	* 0.1791	0.1743	0.1626	0.2067
311	* 0.1606	0.1563	0.1290	@ 0.1346
312	* 0.1576	0.1533	0.1266	0.1478
313	* 0.1131	0.1100	0.1065	0.0993
314	* 0.1466	0.1426	0.1103	0.1013
315	* 0.1359	0.1322	0.0963	0.1146
316	* 0.1330	0.1294	0.0951	0.0974
317	* 0.1304	0.1269	0.1000	0.1101
318	* 0.1053	0.1025	0.0775	0.0763
319	* 0.0986	0.0959	0.0826	0.1032
320	* 0.1131	0.1100	0.1018	0.0929
321	* 0.1207	0.1174	0.0988	0.1093
322	* 0.1461	0.1421	0.1612	0.1800
323	* 0.1794	0.1745	0.1490	0.1065
324	0.1366	0.1371	0.1184	@ 0.1362
325	0.1403	0.1212	0.1065	0.1276
326	0.1936	0.1527	0.1340	0.1368
327	0.2856	0.1807	0.1885	0.2551
328	0.1428	0.1460	0.1281	0.0964
329	0.1476	0.1423	@ 0.1433	@ 0.1540
330	0.1234	0.1193	0.1048	@ 0.1540
331	0.1594	0.1374	0.1367	@ 0.1540
332	0.1879	0.1996	0.2117	@ 0.1540
333	0.1857	0.1892	0.1594	@ 0.1540
334	0.3066	0.1515	0.1447	@ 0.1540
335	0.1737	0.1527	0.2857	
336	0.1535	0.1424	0.1282	
337	0.1353	0.1270	0.1191	
338	0.1399	* 0.1361	0.1124	
339	0.1553	* 0.1511	0.0699	
340	0.2052	* 0.1997	0.1148	
341	0.1206	* 0.1173	0.1443	
342	0.2007	* 0.1953	0.2655	
343	0.1789	* 0.1741	0.1200	
344	0.1442	* 0.1403	0.1154	
345	0.1098	* 0.1068	0.1110	

Appendix B (continued)

Day	Wahweap (49)	Padre Bay (47)	Bullfrog Bay (1)	Hite (3)
346	0.1024	*0.0996	0.0982	
347	0.2732	*0.2658	0.2145	
348	0.2219	*0.2159	0.1468	
349	0.1060	*0.1031		
350	0.0984	*0.0957		0.0932
351	0.1560	*0.1518		0.1251
352	0.1384	*0.1347		0.1173
353	0.1074	*0.1045		0.1057
354	0.1049	*0.1021		@0.1183
355	0.0767	*0.0746		0.1262
356	0.1602	*0.1559		
357	0.2184	*0.2125		
358	0.1930	*0.1878		
359	0.1603	*0.1560		
360	0.1227	*0.1194		
361	0.1094	*0.1064		
362	0.1052	*0.1024		
363	@0.1387	*0.1350		
364	@0.1387	*0.1350		
365	@0.1387	*0.1350		

Calculated using one or more meteorologic parameters not measured at raft and obtained elsewhere.

@ Estimated from preceding and following days.

* Estimated from data at another raft station.

APPENDIX C: 1963-1976 EVAPORATION STUDY

Explanation of Column Headings

Month (1-12) refers to January through December.

Inflow is streamflow into the reservoir (measured in acre-feet).

PPT(FT) is precipitation (measured in feet).

TOT(FT) is the total precipitation (measured in acre-feet).

TOT Inflow is the sum of the total precipitation and the inflow (measured in acre-feet).

Outflow is the amount of water which flows from the reservoir (measured in acre-feet).

Vol Change is the change in the amount of water stored in the reservoir (measured in acre-feet).

Evaporation is the evaporative loss (measured in acre-feet).

Bank Storage is the monthly change in the amount of water retained as bank storage in the reservoir (measured in acre-feet).

Cum B.S. is the cumulative bank storage since the reservoir was created (measured in acre-feet).

LAKE POWELL EVAPORATION STUDY -- 1963

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1									
2									
3									
4									
5									
6									195213.
7	252219.	0.0199	416.39	252635.	90000.	40000.	19414.64	103220.	298434.
8	353700.	0.0658	1444.05	355144.	62000.	220000.	15500.73	57643.	356078.
9	381900.	0.0599	1439.99	383340.	60000.	269000.	15260.00	39080.	395158.
10	215112.	0.0274	703.03	215815.	61000.	109000.	13464.23	32351.	427509.
11	313536.	0.0283	756.21	314293.	60000.	185000.	12744.47	56548.	484057.
12	295580.	0.0441	1230.26	296810.	63000.	139000.	12488.32	82322.	566380.

LAKE POWELL EVAPORATION STUDY -- 1964

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	301478.	0.0133	384.46	301863.	71000.	143000.	4998.06	82864.	649245.
2	286929.	0.0249	733.49	287662.	231000.	6000.	5183.40	45479.	694724.
3	316763.	0.0308	892.16	317655.	388000.	-134000.	7523.10	56132.	750856.
4	391172.	0.0299	817.94	391990.	771000.	-358000.	9883.56	-30893.	719962.
5	1556212.	0.0425	1289.66	1557501.	319000.	1173000.	13351.79	52149.	772112.
6	1737491.	0.0108	436.96	1737928.	60000.	1468000.	25343.82	184584.	956696.
7	865608.	0.0199	957.49	866565.	60000.	567000.	38698.95	200866.	1157562.
8	625624.	0.0658	3336.76	628961.	174000.	305000.	44349.38	105611.	1263174.
9	381900.	0.0599	2917.49	384817.	156000.	72000.	39386.25	117431.	1380605.
10	422032.	0.0274	1341.44	423373.	268000.	11000.	33007.79	111365.	1491971.
11	472802.	0.0283	1470.78	474273.	348000.	-21000.	26474.10	120799.	1612770.
12	548693.	0.0441	2292.69	550986.	398000.	21000.	23272.98	108712.	1721483.

LAKE POWELL EVAPORATION STUDY -- 1965

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	615069.	0.0133	692.13	615761.	558000.	-26000.	8997.73	74764.	1796247.
2	586657.	0.0249	1297.74	587955.	515000.	26000.	11074.13	35880.	1832128.
3	605271.	0.0308	1600.55	606871.	556000.	-11000.	13410.08	48461.	1880589.
4	1185303.	0.0299	1552.64	1186855.	1222000.	-41000.	16345.95	-10490.	1870098.
5	2329532.	0.0425	2199.58	2331731.	2284000.	47000.	22556.55	-21825.	1848273.
6	3447562.	0.0108	596.26	3448158.	2323000.	1049000.	30317.86	45839.	1894112.
7	2219713.	0.0199	1241.59	2220955.	727000.	1248000.	42835.19	203119.	2097232.
8	939159.	0.0658	4344.34	943503.	871000.	27000.	54991.66	-9488.	2087743.
9	827414.	0.0599	3947.39	831362.	750000.	-79000.	52960.95	107400.	2195144.
10	902086.	0.0274	1809.22	903895.	659000.	99000.	34923.52	110972.	2306116.
11	852984.	0.0283	1875.38	854860.	589000.	66000.	32212.46	167647.	2473763.
12	774155.	0.0441	2950.11	777105.	531000.	135000.	29946.42	81158.	2554922.

LAKE POWELL EVAPORATION STUDY -- 1966

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	609825.	0.0133	898.73	610724.	451000.	40000.	11683.53	108040.	2662962.
2	487083.	0.0249	1685.12	488768.	483000.	-54000.	8313.28	51455.	2714417.
3	851781.	0.0308	2084.64	853865.	622000.	156000.	21071.78	54793.	2769211.
4	1023735.	0.0299	2059.50	1025794.	825000.	158000.	30091.58	12703.	2781914.
5	1489955.	0.0425	2990.08	1492945.	978000.	395000.	33535.88	86409.	2868323.
6	967236.	0.0108	776.20	968012.	754000.	21000.	52782.15	140230.	3008553.
7	480302.	0.0199	1415.69	481718.	658000.	-346000.	58987.50	110730.	3119283.
8	375957.	0.0658	4506.29	380463.	682000.	-411000.	63088.08	46375.	3165659.
9	377295.	0.0599	3983.69	381279.	622000.	-298000.	47804.39	9474.	3175133.
10	494158.	0.0274	1787.49	495946.	551000.	-156000.	36725.00	64221.	3239354.
11	418857.	0.0283	1803.13	420660.	584000.	-223000.	34206.50	25454.	3264808.
12	425327.	0.0441	2760.19	428087.	529000.	-139000.	28018.58	10068.	3274877.

LAKE POWELL EVAPORATION STUDY -- 1967

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	422090.	0.0133	818.46	422909.	617000.	-245000.	10640.06	40268.	3315145.
2	391532.	0.0249	1507.24	393039.	534000.	-139000.	10651.23	-12611.	3302533.
3	532231.	0.0308	1831.49	534062.	690000.	-155000.	16137.00	-17074.	3285458.
4	445028.	0.0299	1740.14	446768.	788000.	-302000.	23201.99	-62433.	3223024.
5	1009350.	0.0425	2442.89	1011793.	879000.	104000.	22465.09	6328.	3229352.
6	2058000.	0.0108	666.30	2058666.	698000.	1228000.	36646.73	96019.	3325372.
7	1020615.	0.0199	1315.79	1021931.	641000.	225000.	48574.94	107356.	3432728.
8	629495.	0.0658	4344.34	633839.	693000.	-133000.	47567.79	26271.	3458999.
9	560336.	0.0599	3911.69	564248.	596000.	-131000.	42213.75	57034.	3516033.
10	490611.	0.0274	1781.99	492393.	415000.	-19000.	37476.00	58917.	3574950.
11	560141.	0.0283	1835.99	561977.	460000.	6000.	37044.00	58933.	3633883.
12	549756.	0.0441	2853.38	552610.	552000.	-77000.	28964.57	48645.	3682529.

LAKE POWELL EVAPORATION STUDY -- 1968

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	516482.	0.0133	853.59	517336.	633000.	-128000.	11096.80	1239.	3683768.
2	465961.	0.0249	1595.62	467557.	464000.	57000.	11275.75	-64718.	3619049.
3	479277.	0.0308	1938.95	481216.	858000.	-346000.	17817.41	-48601.	3570447.
4	541969.	0.0299	1819.94	543789.	968000.	-383000.	20019.44	-61230.	3509216.
5	1483033.	0.0425	2593.98	1485627.	943000.	488000.	26804.53	27822.	3537038.
6	2805510.	0.0108	732.55	2806242.	894000.	1675000.	45136.33	192105.	3729144.
7	954183.	0.0199	1450.59	955634.	827000.	-65000.	51979.82	141654.	3870798.
8	932385.	0.0658	4789.70	937174.	685000.	190000.	46987.60	15187.	3885985.
9	488961.	0.0599	4352.09	493314.	635000.	-240000.	57060.85	41253.	3927238.
10	542637.	0.0274	1964.32	544601.	620000.	-144000.	35357.85	33243.	3960481.
11	605095.	0.0283	1999.19	607094.	616000.	-120000.	38690.39	72404.	4032885.
12	542312.	0.0441	3078.63	545391.	639000.	-168000.	31251.07	43139.	4076024.

LAKE POWELL EVAPORATION STUDY -- 1969

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	657021.	0.0458	3184.95	660206.	570000.	63000.	12044.93	15161.	4091186.
2	657063.	0.0399	2805.19	659868.	461000.	190000.	12389.63	-3521.	4087664.
3	739482.	0.0508	3597.72	743079.	708000.	49000.	17575.78	-31496.	4056168.
4	1521169.	0.0083	608.37	1521777.	871000.	660000.	26099.28	-35322.	4020845.
5	2303820.	0.0266	2118.00	2305938.	763000.	1506000.	37528.31	-590.	4020254.
6	1765407.	0.0133	1146.53	1766553.	875000.	732000.	51307.35	108245.	4128500.
7	1195553.	0.0283	2497.58	1198051.	956000.	44000.	63027.25	135023.	4263524.
8	626592.	0.0908	7918.39	634510.	930000.	-402000.	65962.42	40547.	4304071.
9	676607.	0.0241	2065.88	678673.	794000.	-222000.	58628.45	48044.	4352115.
10	883168.	0.1091	9279.71	892447.	630000.	136000.	42715.00	83732.	4435847.
11	754086.	0.0266	2273.06	756359.	706000.	-59000.	41909.66	67449.	4503296.
12	680567.	0.0199	1695.39	682262.	814000.	-179000.	38005.21	9257.	4512553.

LAKE POWELL EVAPORATION STUDY -- 1970

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	529068.	0.0225	1880.88	530949.	706000.	-226000.	14489.79	36459.	4549012.
2	548437.	0.0733	6095.83	554533.	445000.	58000.	14685.41	36847.	4585859.
3	593402.	0.1116	9334.77	602736.	486000.	101000.	26820.06	-11083.	4574775.
4	578199.	0.0116	964.48	579163.	942000.	-389000.	32930.21	-6766.	4568008.
5	2341398.	0.0000	0.00	2341398.	900000.	1324000.	42375.59	75022.	4643030.
6	2636984.	0.0149	1402.94	2638387.	800000.	1590000.	61495.96	186890.	4829920.
7	1194446.	0.0433	4267.03	1198713.	769000.	176000.	69913.68	183799.	5013719.
8	581110.	0.0441	4337.16	585447.	773000.	-294000.	72995.31	33451.	5047170.
9	1010455.	0.0033	325.53	1010780.	701000.	98000.	76988.62	134792.	5181962.
10	751922.	0.0116	1145.66	753067.	498000.	89000.	50327.50	115740.	5297702.
11	742526.	0.0399	3949.59	746476.	459000.	105000.	48547.16	133928.	5431630.
12	658233.	0.0191	1892.51	660126.	670000.	-107000.	44268.42	52857.	5484487.

LAKE POWELL EVAPORATION STUDY -- 1971

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	684290.	0.0000	0.00	684290.	492000.	99000.	17114.93	76175.	5560662.
2	654046.	0.0066	661.90	654708.	416000.	186000.	17540.35	35167.	5595829.
3	711179.	0.0116	1164.74	712343.	640000.	19000.	27038.64	26304.	5622133.
4	1070737.	0.0149	1501.64	1072238.	1011000.	78000.	39710.29	-56471.	5565661.
5	1527533.	0.0083	845.83	1528379.	926000.	520000.	41953.32	40425.	5606086.
6	2459153.	0.0116	1243.43	2460396.	894000.	1286000.	71142.14	209253.	5815339.
7	1157908.	0.0083	918.91	1158827.	943000.	1000.	99518.67	115308.	5930647.
8	608205.	0.0725	7911.19	616116.	876000.	-380000.	83567.71	36548.	5967195.
9	607535.	0.0166	1785.25	609320.	776000.	-329000.	72481.14	89839.	6057034.
10	651417.	0.0641	6818.35	658236.	584000.	-10000.	53484.20	30751.	6087785.
11	696288.	0.0208	2201.97	698490.	764000.	-183000.	51966.70	65523.	6153308.
12	711408.	0.0758	7908.27	719317.	937000.	-299000.	46754.43	34562.	6187870.

LAKE POWELL EVAPORATION STUDY -- 1972

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	692681.	0.0000	0.00	692681.	806000.	-174000.	17881.93	42798.	6230668.
2	663098.	0.0000	0.00	663098.	444000.	169000.	18225.81	31872.	6262540.
3	715744.	0.0000	0.00	715744.	378000.	337000.	28243.85	-27499.	6235040.
4	544906.	0.0016	174.28	545080.	782000.	-225000.	46620.78	-58540.	6176499.
5	1132962.	0.0000	0.00	1132962.	902000.	139000.	50019.32	41943.	6218442.
6	1825373.	0.0775	8302.18	1833675.	863000.	820000.	63828.64	86846.	6305288.
7	555592.	0.0208	2249.47	557841.	915000.	-448000.	80891.26	9950.	6315238.
8	415633.	0.0625	6570.93	422204.	1005000.	-664000.	67724.46	13479.	6328717.
9	418738.	0.0458	4664.68	423403.	931000.	-583000.	69885.50	5517.	6334234.
10	1014414.	0.3258	33161.68	1047576.	631000.	580000.	54110.36	-217534.	6116699.
11	845278.	0.0824	8533.79	853812.	671000.	44000.	50858.00	87954.	6204653.
12	692265.	0.0725	7438.86	699704.	1017000.	-341000.	46001.24	-22296.	6182356.

LAKE POWELL EVAPORATION STUDY -- 1973

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	690583.	0.0499	5019.49	695602.	1207000.	-518000.	17400.93	-10798.	6171557.
2	678185.	0.0433	4290.43	682475.	764000.	-36000.	17491.76	-63016.	6108540.
3	750438.	0.1091	10720.16	761158.	1095000.	-251000.	21113.00	-103955.	6004585.
4	897418.	0.0299	2858.54	900277.	1678000.	-715000.	33508.55	-96231.	5908353.
5	3152296.	0.0641	6435.27	3158731.	648000.	2601000.	39280.25	-129549.	5778803.
6	3251121.	0.0625	7078.12	3258199.	751000.	2252000.	67006.25	188192.	5966995.
7	1955092.	0.0425	5166.51	1960259.	656000.	935000.	85399.40	283859.	6250854.
8	903354.	0.0399	4973.79	908327.	567000.	149000.	93362.35	98965.	6349819.
9	726109.	0.0108	1353.89	727463.	424000.	92000.	89565.40	121897.	6471716.
10	679795.	0.0041	520.72	680316.	510000.	-23000.	76443.03	116873.	6588588.
11	746379.	0.0325	4072.08	750451.	412000.	131000.	61812.18	145639.	6734227.
12	720980.	0.0000	0.00	720980.	333000.	253000.	56426.89	78553.	6812780.

LAKE POWELL EVAPORATION STUDY -- 1974

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	711559.	0.0908	11496.32	723055.	846000.	-222000.	32801.42	66254.	6879034.
2	559501.	0.0033	420.81	559921.	299000.	178000.	36600.53	46321.	6925355.
3	756829.	0.0258	3294.26	760123.	388000.	338000.	34600.42	-477.	6924877.
4	731933.	0.0116	1502.66	733436.	494000.	154000.	50403.72	35032.	6959909.
5	2252397.	0.0008	110.29	2252507.	804000.	1321000.	60825.85	66681.	7026590.
6	1822271.	0.0000	0.00	1822271.	914000.	686000.	88343.59	133927.	7160517.
7	740494.	0.0333	4573.83	745068.	1226000.	-642000.	91202.25	69865.	7230382.
8	440793.	0.0291	3897.68	444691.	1213000.	-911000.	101473.50	41217.	7271599.
9	391109.	0.0124	1626.06	392735.	826000.	-533000.	87438.79	12297.	7283896.
10	555643.	0.0999	12815.99	568459.	602000.	-130000.	56240.88	40218.	7324114.
11	650049.	0.0274	3506.79	653556.	710000.	-160000.	51868.75	51687.	7375801.
12	525296.	0.0124	1585.99	526882.	564000.	-152000.	48542.17	66339.	7442140.

LAKE POWELL EVAPORATION STUDY -- 1975

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	580459.	0.0249	3140.24	583599.	768000.	-314000.	21772.39	107826.	7549966.
2	538379.	0.0808	10076.68	548455.	556000.	-55000.	22023.26	25432.	7575398.
3	606184.	0.0375	4686.56	610870.	508000.	95000.	33847.39	-25976.	7549421.
4	710391.	0.0000	0.00	710391.	459000.	215000.	38407.12	-2015.	7547405.
5	1909249.	0.0425	5474.00	1914723.	892000.	1006000.	39606.00	-22882.	7524522.
6	3047442.	0.0158	2147.07	3049589.	987000.	1805000.	76503.81	181085.	7705607.
7	2340398.	0.0483	6871.06	2347269.	1221000.	839000.	98564.26	188704.	7894311.
8	743683.	0.0375	5368.12	749051.	1022000.	-418000.	93047.48	52004.	7946315.
9	539614.	0.0399	5633.19	545247.	966000.	-539000.	89074.96	29172.	7975487.
10	508347.	0.0066	925.66	509273.	637000.	-208000.	70466.37	9806.	7985293.
11	662893.	0.0041	577.16	663470.	425000.	81000.	68105.67	89365.	8074658.
12	740123.	0.0099	1391.79	741515.	520000.	101000.	62399.03	58115.	8132773.

LAKE POWELL EVAPORATION STUDY -- 1976

MONTH	INFLOW	PPT (FT)	TOT FT	TOT INFLOW	OUTFLOW	VOL CHANGE	EVAPORATION	BANK STORAGE	CUM B.S.
1	629753.	0.0000	0.00	629753.	692000.	-154000.	24124.53	67628.	8200401.
2	574588.	0.0641	8867.51	583455.	742000.	-184000.	24414.44	1040.	8201441.
3	585185.	0.0675	9283.95	594469.	676000.	-101000.	37365.03	-17896.	8183544.
4	589949.	0.0525	7203.52	597153.	660000.	-73000.	51453.75	-41300.	8142243.
5	1602690.	0.0499	6909.74	1609599.	1046000.	495000.	60805.79	7793.	8150036.
6	1509000.	0.0000	0.00	1509000.	756000.	621000.	88722.89	43276.	8193312.
7	650811.	0.0883	12498.28	663309.	766000.	-251000.	108711.46	39597.	8232909.
8	460147.	0.0000	0.00	460147.	720000.	-414000.	106977.59	47169.	8280078.
9	439460.	0.0516	7123.02	446583.	842000.	-474000.	98573.46	-19990.	8260087.
10	509529.	0.0191	2604.84	512134.	769000.	-375000.	72256.14	45878.	8305965.
11	571701.	0.0091	1222.00	572923.	899000.	-448000.	65544.07	56379.	8362344.
12	571026.	0.0000	0.00	571026.	811000.	-341000.	58895.30	42131.	8404476.

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